NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A BIOECONOMIC ANALYSIS OF FISHERY MANAGEMENT

by

Albert Ray Costa

June 1995

Principal Advisor:	Katsuaki L. Terasawa
Associate Advisor:	Bill Gates

Approved for public release; distribution unlimited

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1995

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
A BIOECONOMIC ANALYSIS OF FISHERY MANAGEMENT

5. FUNDING NUMBERS

6. AUTHOR(S)
Costa, Albert R

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Throughout history, the effective management of common-property resources has continually eluded mankind. Typically, the problem of overutilization and overcapitalization of the world's fisheries has been approached from purely a biological standpoint. Little, if any, economic consideration has gone into the traditional modes of common recourse management. Consequently, existing programs have *not* been notably successful from both an economic or biological point of view. The purpose of this paper is to provide the reader with the economic foundations of the common-property fisheries and to examine the implications of possible management strategies. It is hoped that with a theory of resource regulation capable in principle of predicting the reactions of the fishing industry, that the types of controls that are most likely to be successful in achieving biologically and economically desirable objectives can be identified.

14. SUBJECT TERMS
Fishery Management, Economics, Optimum Sustainable Yield, Common Property Resources, Total Quota, Allocated Quota

15. NUMBER OF PAGES
67

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Approved for public release; distribution is unlimited

A BIOECONOMIC ANALYSIS OF FISHERY MANAGEMENT

Albert R. Costa
Lieutenant, United Sates Navy
B.S., San Diego State University, 1989

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 1995

Author: Albert R. Costa

Approved by: Katsuaki L. Terasawa, Principal Advisor

Bill Gates, Associate Advisor

David R. Whipple, Chairman Department of Systems Management

ABSTRACT

Throughout history, the effective management of common-property resources has continually eluded mankind. Typically, the problem of overutilization and overcapitalization of the world's fisheries has been approached from purely a biological standpoint. Little, if any, economic consideration has gone into the traditional modes of common recourse management. Consequently, existing programs have *not* been notably successful from both an economic or biological point of view. The purpose of this paper is to provide the reader with the economic foundations of the common-property fisheries and to examine the implications of possible management strategies. It is hoped that with a theory of resource regulation capable in principle of predicting the reactions of the fishing industry, that the types of controls that are most likely to be successful in achieving biologically and economically desirable objectives can be identified.

TABLE OF CONTENTS

I. INTRODUCTION 1

A. BACKGROUND 1

B. OBJECTIVES OF THIS RESEARCH 3

C. THE RESEARCH QUESTION 3

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS 3

E. RESEARCH METHODOLOGY 4

F. ORGANIZATION OF THE STUDY 5

II. FISHERIES AS COMMON PROPERTY RESOURCES 7

A. CHARACTERISTICS 7

B. ECONOMIC AND CONSERVATION INEFFICIENCY 8

C. HISTORY OF EXPLOITATION 9

D. SUBSIDIZED EXPLOITATION 11

III. FISHERY MANAGEMENT OBJECTIVES 13

A. MAXIMUM SUSTAINABLE YIELD 13

B. MAXIMUM ECONOMIC YIELD 17

IV. FISHERY MODEL 19

A. BASIC BIOLOGIC MODEL 19
1. Growth 20
2. Harvesting 24
3. Fishing Effort 27

B. BASIC ECONOMIC MODEL 28

V. UNREGULATED FISHERY ECONOMICS 29

A. SOLE-OWNER EFFORT 29

B. OPEN-ACCESS EFFORT 30

VI. REGULATED FISHERY ECONOMICS 33

A. MAGNUSON FISHERY CONSERVATION AND MANAGMENT ACT 35

B. PHYSICAL CONTROLS 36

C. TAXES AND ROYALTIES 39

D. LIMITED ENTRY VIA VESSEL/OWNER LICENSES 41

E. TOTAL QUOTA SYSTEM 43

F. ALLOCATED QUOTA SYSTEM 46

VII. CONCLUSION 51

LIST OF REFERENCES 55

BIBLIOGRAPHY 57

INITIAL DISTRIBUTION LIST 59

I. INTRODUCTION

A. BACKGROUND

The sea has always been an important food source for the world's population and with the increasing awareness of the health benefits of fish, the demands placed on the oceans' resources continue to increase. Last year, in the United States alone, annual per capita seafood consumption exceeded 14 pounds (Alden, 1994). Other countries such as Japan, the Philippines, Cambodia, Taiwan, Hong Kong, Norway, Iceland, Denmark, Sweden, and Portugal have historically out paced the U.S. per capita consumption of fish by at least four or five times. To meet this demand, further growth in production is expected. Figure 1.1 indicates the substantial rise in worldwide catch over the last 35 years. For all U.S. fisheries, the average yearly yield from 1989 to 1991, was roughly 6.6 million metric tons (mmt), placing the U.S. sixth in terms of total catch among fishing nations. In doing so, the U.S. fishing industry generated revenues of nearly $4 billion in 1991. This translates into tens of billions of dollars impacting the U.S. economy through related efforts such as ship building, the manufacture of fishing equipment, marketing, etc. Annual worldwide fishing revenues are estimated to be in excess of $64 billion. In addition, a number of nations, such as Japan, Canada, Peru, Denmark, and Iceland, are notably dependent on foreign sales. For instance, "over 90 percent of the value of Iceland's exports...is fishery products." (Bell, 1978) The United States likewise prospers from the export market, annually exporting nearly $1 billion worth of fishery products to Japan alone. (Swartz and Sissenwine, 1993)

However, this perception of limitless wealth has encouraged excessive harvesting of select species without thought for the long-term repercussions on the world food supply or on world economics. As the twentieth century draws to a close, it is now clear that years of uncontrolled exploitation have severely scarred the world's fishery resources. A number of global fish stocks have been depleted to the point where they are now in danger

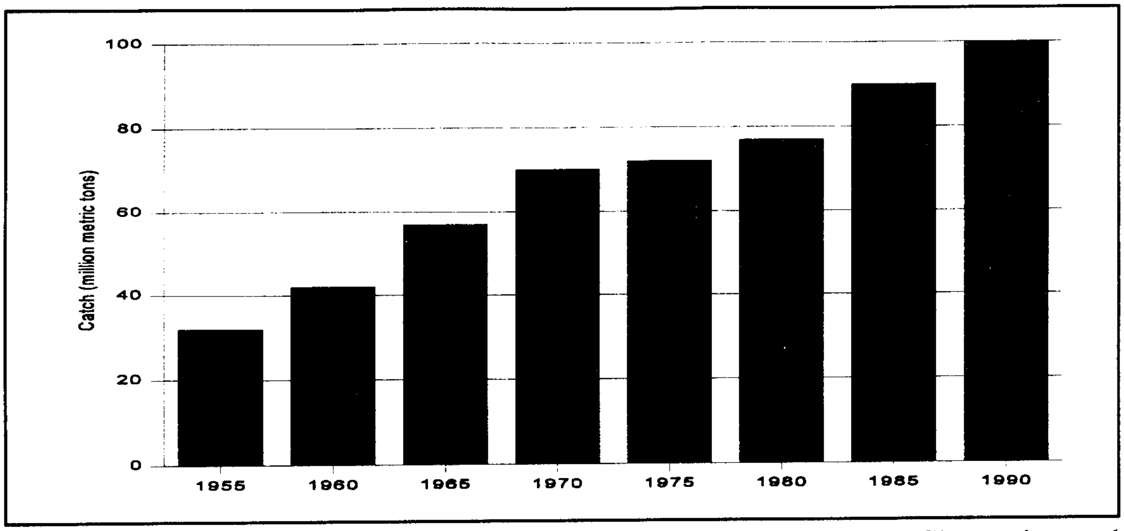


Figure 1.1: Worldwide fishery catch from 1955 to 1990. From Sissenwine and Rosenberg (1993).

of extinction. Accompanying the biological problems with common marine fisheries is the economic dilemmas that inevitably arise. Because of the common-property, open-access nature of nearly all marine stocks, fisheries tend to become economically less profitable as more and more effort is expended to capture additional shares of the rent. And though this added effort can come in a number of forms, the result is the same. The inefficient employment of capital and labor continues until the fishery's total cost of capture equals the total revenues generated from sales, and in some cases actually exceeds these gains.

Of course, when such frequent situations occur, the initial reaction of the uninformed producer is to quickly condemn harvesting by foreign fleets or government intervention for the lack of profitability. In actuality, such criticisms should be directed within. Some form of resource ownership, via government regulations, is necessary to *end* the wasteful cycle of overcapitalization and overexploitation. Although the management of a highly variable a marine stock presents a complex mixture of economic, biological, social, and political factors, this subject has and will continue to come under growing pressures as the difficulties escalate.

B. OBJECTIVES OF THIS RESEARCH

Most published evaluations of fisheries economics have argued the pros and cons of two contrasting systems of property rights; sole ownership verses open-access. Little regard has been directed to the case of limited access, and it is this omission that the offered text attempts to correct. This paper not only considers the economic and biological implications of the often used management strategies, but also studies the effects of less regarded tactics. Catch taxes, allocated quotas, and limited entry programs are commonly despised by commercial fishermen and thus given little consideration since their enactment is rare. Further scrutiny may reveal that these controls offer the greatest potential to generate significant long-run economic and biological benefits.

C. THE RESEARCH QUESTION

As already alluded to, the primary research question is to determine which, if any, of the fishery management schemes addressed will best serve to meet long-term economic and biological goals. In other words, which design will compel common-property users to act in an *optimal* manner. By optimal manner, it is implied that the most efficient quantity of inputs, labor and capital, are applied to the fishery. The chief objective then being the obtainment of the maximum economic yield (MEY). Though, the theory of maximum sustainable yield (MSY) will also be discussed.

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

Research will focus on the effects of various control measures in an attempt to determine the *best* effort reducing constraint. This paper should be considered an introduction to the theory of limited-entry fishery management, since many important complications are not discussed. In particular, only a simple deterministic model is provided; more complex models would involve a much more exhausting analysis. For simplicity purposes, many important aspects of the problem are ignored or are only given non-analytical commentary. For instance, alternative objectives, stochastic influences,

stock fluctuations and uncertainty, effects of multi-species, processing and distribution problems, and political factors are largely neglected. Likewise, the possibility of cooperation between producers (coalition building) is not considered for purposes of this discussion.

Many of these limitations are evident in the following assumptions. For one, it is assumed that with exclusive rights to a fishery's resources, the goal of a sole-owner would be to maximize profits. It is also assumed that a fishery's participants, even sole-owners, are *price takers* facing a fixed and constant price; not possessing the market controls granted a monopolist. Similarly, the cost per unit of effort is assumed constant. With an indefinite time horizon, a number of proportionality assumptions are also made in developing the basic model. Growth and mortality rates, as well as the catch-per-unit-effort, are all assumed proportional to population mass. While these are the primary limitations and assumptions, others of lesser impact will be introduced throughout the course of this text.

E. RESEARCH METHODOLOGY

A comprehensive review of the applicable literature was conducted utilizing the resources available from the Naval Postgraduate School (Knox) Library, the city of Monterey Library, and the San Diego County Library system. Information was also obtained from the United States Interior Department of Fish and Wildlife Service and the California Department of Fish and Game. Unfortunately, the information provided by these agencies was largely promotional and thus of little use in this economic analysis.

Of significant importance to this text were the works of Colin W. Clark, Lee G. Anderson, and Fredrick W. Bell. Clark's publications, *Mathematical Bioeconomics* (1990) and *Bioeconomic Modeling and Fisheries Management* (1985), provided the basis for the fishery management models presented in Chapter 5 and 6. Anderson's edition of *The Economics of Fisheries Management* (1977) was enormously valuable in the discussion of the viable goals for resource management. Lastly, Bell's *Food From the Sea* (1978) provided countless examples of biological tragedy for study.

F. ORGANIZATION OF THE STUDY

The organization of this text is divided into seven chapters. Chapter II offers a detailed look at the characteristics of common-property resources and their inherent problems. Also included in this section are a few illustrations of worldwide overexploitation and a short discussion on the role that government subsides play in the fishing industry. Chapter III moves into the possible objectives of fishery management systems, including the theories of MSY and MEY. The basic fishery model is presented in Chapter IV. Chapter V focuses on the unregulated economics of open-access and solely owned fisheries. Analytically explored are the reasons why unmanaged common-property resources will not operate in an optimal manner and how exclusive access rights avoid the inefficient use of capital and labor. The main economic evaluation of the various controls to restrict user effort is detailed in Chapter VI. Drawing from the discussions presented in Chapters IV and V, this analysis concentrates on the effects that each measure would have on stock preservation and, equally as important, profit generation. Chapter VII concludes with recommendations on the management strategies that will best serve to meet the long-term objectives of fishery management in the future.

II. FISHERIES AS COMMON PROPERTY RESOURCES

A. CHARACTERISTICS

What exactly is a fishery? Many definitions abound, but Anderson (1977) probably says it best, "...a fishery can be thought of as a stock or stocks of fish and the enterprises that have the potential of exploiting them." Christy and Scott (1965) go on to add that "a BASIC characteristic of all fisheries is that they are common property natural resources." In fact, all wildlife stocks are common property because like many other common property resources, such as air, large bodies of water, and flowing streams, they can be exploited[1] by more than one enterprise at a time and without cost. In addition, since no individual user has to pay for the right to use the resource, no single enterprise has exclusive rights to the wealth; nor can lawfully prevent other units from sharing in the bounty.

Under such circumstances, overutilization[2] of the fishery becomes a common occurance. Distinct from industries where private property rights prevail, a producer's productivity in the fishing industry is influenced by the total number of economic units exploiting the common resource. When left unregulated in this environment, producers will attempt to gain a greater share of the product resulting in overfishing and the eventual collapse of the fishery. As Clark (1980) notes, "the tragedy of the commons has proved particularly difficult to counteract in the case of marine fishery resources, where the establishment of individual property rights is virtually out of the question." One reason

[1] The term exploitation as used in the course of this text does not, in itself, infer misuse, but rather the utilization of a common property resource.

[2] The terms overutilization and overexploitation are used to denote that the level of fishing has exceeded the resource's productivity. When fully utilized/exploited a balance between the fishing level and resource productivity has been achieved.

private use rights are not established is that the expense for their defense is deemed to be more costly than the added returns. Thus, public ownership is a rudimentary fact that will continue to influence the economics of fishery management for a long time to come. (Bell, 1978)

B. ECONOMIC AND CONSERVATION INEFFICIENCY

Another unique attribute of a common property resource, such as a fishery stock, is the fact that the amount of fishing effort applied is not subject to the same constraints that regulate the use of a solely owned resource. The optimum input levels of labor and capital applied to privately owned resources, such as farmlands and coal mines, are not applied to fisheries. Since the commercial users of a common fishery are in physical competition with one another, when left unchecked, they will continue to increase their effort to maximize their share of available resources, so long as profit can be gained.[3]

Thus, it is unlikely that individual users will self-impose one-sided constraints to limit their effort in hopes of achieving a greater social good; knowing that other producers would eagerly reap the unharvested resources. Moreover, there is no limit on the number of producers who can participate in an unregulated fishery. As additional speculators enter the market (i.e., the level of fishing effort increases), the marginal and average catch per unit of effort declines until all profit has been dissipated. "With such conditions, with demand increasing, and without controls, it is inevitable that the fishery will not only become depleted but also that the exploration of the fishery will become economically inefficient in its use of labor and capital." (Christy and Scott, 1965)

The reason that these economic and biological inefficiencies develop is the fact that commercial fishermen using public resources "...fail to take into account the costs that their use may impose on other users." (Clark, 1990) Users of these common resources

[3] A technical analysis of the economic shortcomings of unregulated fisheries is presented in Chapter 5.

do not make the most efficient use of labor, capital, and the fishery resource. As a result, national incomes are depressed by diverting valuable resources into unproductive pursuits. Typically accompanying the problem of overutilization is overcapitalization, which occurs when the available resource is exceeded by the harvesting capacity. An expected result of unrestricted participation in fisheries, overcapitalization intensifies the economic woes and in turn escalates the pressure to continue overutilization and resource depletion.

C. HISTORY OF EXPLOITATION

Although many inhabitants of the world have long perceived the oceans as boundless sources of virtually inexhaustible resources, it is now evident to most that these common resources are unprotected from an overabundance of fisherman with little propensity for maintaining sustainable stock yields. History has been remarkably consistent in that common fish stocks are inevitably overexploited, frequently to the point of collapse or extinction. Unfortunately, overexploitation is often undetectable until it is severe and often irreversible. Of the fisheries the United Nations Food and Agriculture Organization evaluates, over 40 percent are described as heavily exploited or entirely depleted (Swartz and Sissenwine, 1993). The National Marine Fisheries Service calculates that at least 45 percent of all U.S. fisheries are currently overfished (Holmes, 1994).

Several major fisheries around the world have been depleted or have completely collapsed largely because of overfishing, though in some cases environmental factors also played a role. A prime example of overharvesting is that of the California sardine. Gulland (1977) discusses the 1936/37 season, when vast fishing fleets once operated out of Monterey and sardines were one of the biggest fisheries in the world, with a peak catch that year of 800,000 tons. The then California Division of Fish and Game (CDFG) issued alerts at the time that the sardine fishery was being overexploited and in danger of collapse. They advocated that annual quotas be established. This was opposed by the fishing industry, which used its own scientists to dispute the CDFG's findings. As a

result, no action was taken to protect the stock. By 1952 the catch was almost nonexistent, as illustrated in Figure 2.1. To this day, the U.S. Pacific coastal sardine stock remains at a comparably low level. (Ludwig, et al., 1993)

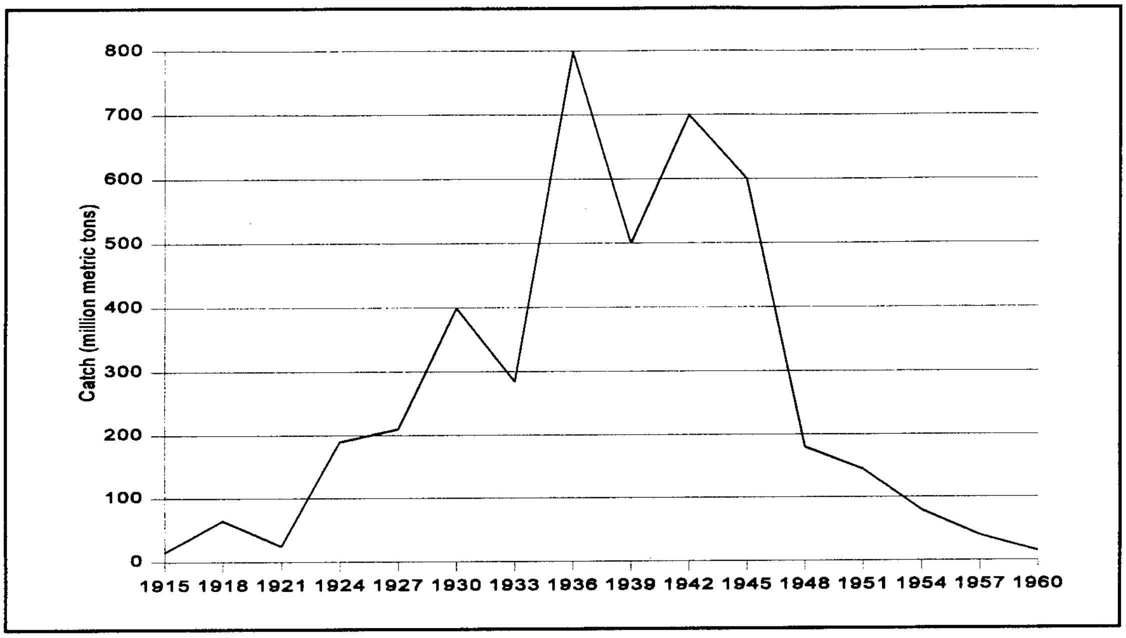


Figure 2.1: Sardine catches off the Pacific coast of the United States. After Gulland (1977).

After the decimation of the California sardine, the vast fishing fleets moved south, targeting the Peruvian anchovy. "The result was the most specular collapse in the history of fisheries exploitation: the yield decreased from a high of [over] 10 million metric tons to near zero in a few years." (Ludwig, et al., 1993) Once the largest single-species fishery in the world, Peruvian anchovy fishery saw production drop from 12.3 million metric tons (mmt) in 1970 to less than 2 mmt by 1973. Within three years, production was off 85 percent from peak levels. However, in defense of the fishing industry, the destruction of the anchovy fishery was a combination of overexploitation and oceanographic phenomena. Specifically, the El Niño currents prompted large fish kills and pushed fish deeper into the sea, where capture is much more demanding. (Bell, 1978)

Other stocks to have been depleted as a result of overfishing include some of the United States' most valuable fishery resources, in particular the North Pacific albacore, Pacific perch, Atlantic menhaden, Atlantic swordfish, Atlantic bluefin tuna, Atlantic sea scallop, New England cod, haddock, and flounder, and many varieties of oyster, clam, and abalone. Figure 2.2 illustrates the exploitation of the New England groundfish, one of the most heavily fished fisheries in the world. Additional stocks like the California sardine and Alaskan rockfish, are no longer considered overutilized, but their populations are below the levels required to generate their long-term potential yields.[4] In the future, such problems are likely to become more critical as demand for food fish increases and as location, catch, and distribution technologies improve. (Swartz and Sissenwine, 1993)

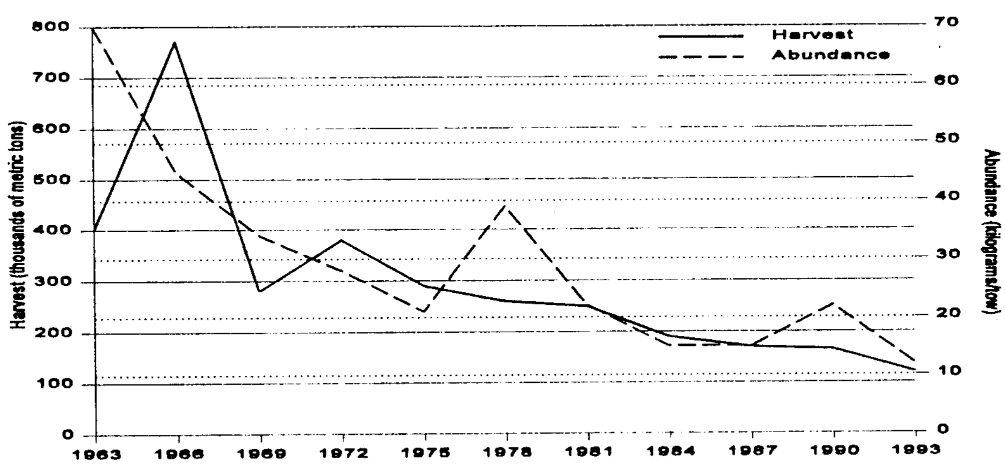


Figure 2.2: The total harvest of groundfish (cod, haddock, flounder, and others) and their total abundance. After Holmes (1994).

D. SUBSIDIZED EXPLOITATION

The United Nations Food and Agriculture Organization has also concluded that fishing expenses are annually exceeding revenues by $16 billion (Sissenwine and

---

[4] The long-term potential yield is the maximum yield that could be taken, year after year, if the fishing effort is fixed at a point where the stock population generates the greatest growth.

Rosenberg, 1993). This deficit occurs because of the overcapitalization of most fisheries today. The incentive is for more and larger vessels to quickly capture a limited amount of fish, to the point where for most investors, fishing is now a losing proposition.

So why does the industry persist in overemploying capital and labor in an unprofitable enterprise rather than disinvesting? In many instances, governments ultimately fund the export of fishery products to delay the unemployment that results when resources become extremely diminished or production becomes prodigal. Unfortunately, added investment in vessels and processing capacity is often encouraged with a run of a few productive years, but when conditions return to normal, the same industry that spurns government intervention appeals for help. Such solicitation, usually with considerable investments and many jobs at risk, often preys on the emotions of the public, which perceive that resources and jobs are being lost to foreign competitors. (Ludwig, et al., 1993)

The standard response by any government is to provide massive amounts of financial support. The United States, for example, has regularly provided relief in the form of low interest loans, credit guarantees, construction subsidies, and federal income tax deferrals to common property fishery users. However, the U.S. is not alone in these anticompetitive practices, where large subsidies are granted to one nation's industry, but not to others having to compete in the same world market. Many nations with market-oriented economies, such as Japan, Canada, and the United Kingdom, have traditionally provided more financial assistance to their commercial fishing industries than the United States. And though these subsidies may originally be deemed temporary, governments go to great lengths to *out subsidize* rival fishing nations, thereby contributing even more to the problem. These governmental policies are in effect encouraging overharvesting and overcapitalization; thus diminishing the resource base. Before any regulatory control can be effectively implemented, such practices must be halted. (Bell, 1978)

III. FISHERY MANAGEMENT OBJECTIVES

With an understanding for the importance of the oceans' resources and an awareness of the economic and environmental problems facing common property resources, it is easy to see why some form of fishery management would be necessary. But before addressing the means of regulating fisheries, the objective of these controls needs to be considered. All too frequently, regulatory agencies attempt to curb the problems associated with public fisheries without a clear understanding for the purpose to be served. A majority of the fishery management programs today reflect the accumulated effects of fragmented retreats from sound management practices in the face of growing pressures from commercial users and conservationists.

The two principle (most frequently discussed) objectives of the fishery management community are variants of the theory of maximum production from the seas. The first, for years advocated by marine biologists, is that fisheries should attempt to maximize their long-term contribution to the world food supply. The second, endorsed by economists, is that the value of the ocean's resources in excess of utilization costs should be maximized. The first goal thereby accentuates the physical volume of production, while the second highlights the importance of the economic rent associated with the oceans' exploitation. However, many scientists that support the physical goal now realize that policy decisions must also consider economic considerations; vigorously opposing conservation strategies that have no clear economic basis.

A. MAXIMUM SUSTAINED YIELD

The scant number of fisheries which currently strive to meet some renewable resource objective, have traditionally based their goals on the concept of maximum sustainable yield (MSY). Though also referred to as the optimum sustainable yield (OSY) in some texts, by either name, its design is to secure the maximum long-term potential

yield from the sea. The basic concept of MSY suggests that the level of catch can be sustained indefinitely if offset, along with natural mortality, by the growth of new fish. Thus, it follows that if the level of effort is constant, the greatest physical yield that a stock can produce year after year is achieved at the population level where the growth rate is greatest.[5] For most fishery stock, the MSY equilibrium is between 40 and 60 percent of their environmental carrying capacity. (Clark, 1990)

By increasing the fishing intensity beyond the point of MSY, i.e., overutilizing the common property resource, the physical yield would annually decline. This occurs, because more and more users, expending a greater effort, are sharing fewer and fewer resources. The Gordon-Schaefer yield curve, illustrated in Figure 3.1, demonstrates how production is affected by an increase in the fishing magnitude beyond the level sustaining the maximum output. Likewise, at these high levels of effort, the growth rate is not able to compensate for the degree of fishing. As a result, the stock population dwindles.

The concept of maximum sustainable yield has some obvious advantages. It provides a very simple and easily understood picture of how fishing effort and fishery stock relate. Any commercial user or law-making body should be able to comprehend that small stock populations supply small yields, and with a little further explanation, that only small yields can be taken from big stocks without long-term depletion. Those who still advocate MSY as a viable goal for fishery management, do so for other reasons as well. Some insist that the oceans' resources are nearly inexhaustible and therefore should be utilized as a substitute for scarce land resources. Others envision that large demands for food in the future necessitate the utmost exploitation of the seas. (Gulland, 1977)

---

[5] Swartz and Sissenwine (1993) estimate that the MSY all U.S. fisheries is approximately 9.5 mmt, or about 40 percent higher than current production.

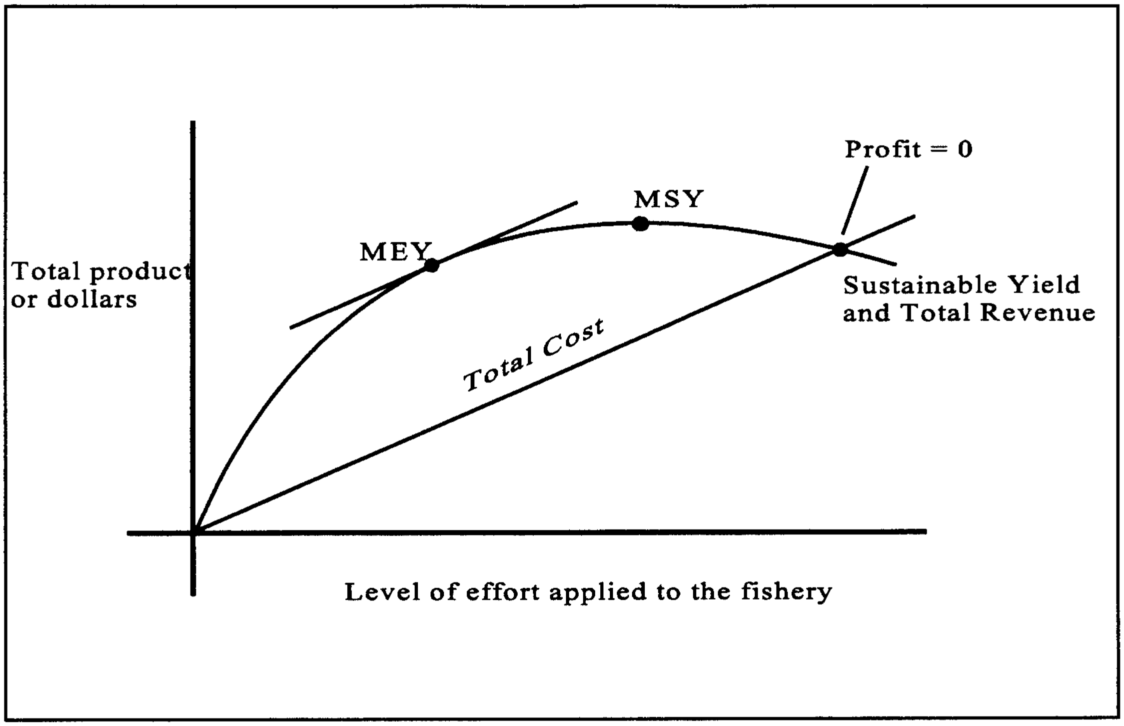


Figure 3.1: Total revenues, costs, and sustainable yield with respect to effort. After Christy and Scott (1965).

For many years, the concept of maintaining resource levels at their MSYs guided fishery management. However, there is now widespread agreement that this concept is no longer acceptable, for various biological and socioeconomic reasons. It is evident that the axiom is far too simplistic to function as a sound operational goal in administering most living resource stocks. McHugh (1984) notes that the MSY concept has at least two basic biological weaknesses which make it difficult to apply in real world situations. For one, many, if not all, renewable resource stocks are subject to wide and unpredictable natural fluctuations. Marine stocks do not behave in a simple way. Thus, the MSY cannot be precisely determined nor, for that matter, be represented by a single value. Yields that can be safely taken when stock levels are high may not be sustained at lower populations. McHugh (1984) also notes stock species are not independent of other stocks. Recruitment rates and the effects of fishing a particular stock, which can be gauged

explicitly under controlled laboratory conditions, may not be accurate assessments for the natural and dynamic environment. Modification of the MSY concept would be required to account for such uncertainties and variations.

As significant as these biological arguments are against MSY, the strongest objections come from economists. They maintain that the attainment of the maximum physical yield makes no economic sense. The concept is clearly addressed solely for the benefits of resource exploitation and completely ignores the cost considerations. Near the maximum of the Schaefer curve, in Figure 4.1, the yield only marginally increases with additional increases in effort. The added effort required to catch the last few fish costs many more times the average cost. These resources could be better used elsewhere. Indeed, pursuing the MSY of a single stock would reduce a producer's total fish yield in comparison with what could be captured with the same effort, but by better balancing between heavily and less heavily utilized stocks. There is no logical connection between the largest possible physical catch and the catch that is most economically desirable. (Gulland, 1997)

In light of these shortcomings, very few marine scientists now defend the MSY concept as the ideal theoretical guide to renewable resource management. Nevertheless, in practice this philosophy can still be functional. If employed as a constraint on exploitation vice an optimal level of capture, the concept may indeed possess worthy elements. As noted earlier, on numerous occasions the commercial fishing effort has surpassed the level yielding the maximum sustained product. This leads to significant depletion of the biological resource as the stock is reduced far below the MSY. When this occurs, the MSY concept may provide the industry with a good and easily grasped rallying point to lessen the level of effort. (Clark, 1990; McHugh, 1984)

Management tactics rooted exclusively in achieving the maximum physical yield will almost certainly breed severe crises because of the concept's economic irrelevance. With a reduction of fishing to the MSY level, the waste of resources such as money,

vessels, and men that might be more productive if used elsewhere, will persist. However, the theory does move the effort level in depleted fisheries in the correct direction. Current debates are now concerned with specifying some effort/population level, to the left of the point of MSY in Figure 3.1, that will provide the greatest good in an economic sense.

B. MAXIMUM ECONOMIC YIELD

Economic studies have long proposed the substitution of the maximum sustainable yield with the maximum net economic yield as the proper aim of fishery management. The basic difference between the purely biological theory of the maximum sustainable physical yield and the maximum sustainable economic yield is that the former considered only the resource population, whereas the true goal of management should be to provide the greatest benefit to man. The concept of MEY dictates that the economic rent, the difference between revenues and costs, of the individual users and the net contribution of the fishery to the economy should be maximized. (McHugh, 1984)

Economists advance the idea that to efficiently use labor and capital, the level of catch should equal the point of rent maximization; a total catch below the point of MSY. The maximum net economic revenue is identified by extending the total cost curve, as seen in Figure 4.1, to a point of tangency with the production function. In this illustration, the assumption is that the cost function is linear and runs through the origin, which is rarely the case. But regardless of the cost curve's representation, the advantages of providing higher rent are the same: better profit for the users, cheaper fish for the consumers, and less governmental aid. (McHugh, 1984; Bell, 1978)

This is the principal justification for adopting MEY as the capture quantity for optimum management. However, such a restriction has scientific and biological advantages, as well. The maximum physical output occurs at a high level of effort where the yield curve is flat; the point of maximum profit occurs at a lower level of effort where the yield curve slopes more steeply. Thus, better information may be available to

marine scientists for determining the catch consistent with MEY, than to determine the catch providing the MSY. Likewise, holding the catch at a level below maximum physical output provides conservationists with a safety factor against the unpredictable stock fluctuations that could lead to overfishing. (Gulland, 1977)

While the objective of rent-maximization is not open to many of the same criticisms leveled against the goal of maximum physical yield, there are several difficulties associated with its achievement. For one, it has been denounced by Clark (1985) because of the imprecision in determining the opportunity cost of capital. The concept has also been attacked because it hinges on the unit cost of the fishing effort and the price of the fish captured. These values can vary from year to year and from nation to nation. Hence, the concept does not furnish a permanently fixed level of effort for determining management action. (Gulland, 1977)

Still another difficulty of using net economic yield as an objective lies in the transition of producers already excessively utilizing labor and capital. To achieve a maximum economic rent, some of the surplus elements of production would have to be eliminated. For instance, it may be necessary to reduce the number of vessels exploiting the common property resource by a large percentage. From an economics perspective, society may be better off because of improved efficiency, but the social and political hardships, even though transitional, may be difficult to shoulder. Nevertheless, the concept of MEY would promote the movement of producer effort in the optimum economic direction. (Christy and Scott, 1965)

IV. FISHERY MODEL

Now with some idea of the viable objectives of fishery management, a model reflecting the relationship between fishing effort and other variables is needed in order to make sound predictions. Specifically, a model is needed to determine how resource populations and profits are affected by changes in the effort level. Likewise, the effects of possible management actions, such as constraints on the amount of fishing, sizes of fish caught, or number of speculators exploiting the resource can also be measured. In fact, a wide range of conceivable ventures can be evaluated. If the model is effective, the predicted outcomes will correspond closely to the actual events. However, given the complexities of any natural system, such as a fish stock, and the myriad of unknowns that might affect it, no model can present an entirely accurate prediction of future events. The chief requirement of a model in the course of this text is that it should provide a reasonably accurate assessment of alternative management actions.

A. BASIC BIOLOGIC MODEL

The ensuing model, a composite of the works of Clark (1990), Clark (1985), Gulland (1977), and Anderson (1977), consists of a series mathematical expressions which represent the biological phenomena occurring in fisheries worldwide. By treating the fish population as a unit, considering only changes in total biomass without regard for its structure (age, composition, etc.), the model remains relatively basic. Its equations are

$$\frac{dx}{dt} = G(x) - h(x), \qquad x(0) = x_0, \tag{4.1}$$

$$h(t) = q \cdot E(t) \cdot x(t), \tag{4.2}$$

$$x(t) \geq 0, \tag{4.3}$$

$$\pi(x(t),E(t)) = p \cdot h(t) - c \cdot E(t) = [p \cdot q \cdot x(t) - c] \cdot E(t), \tag{4.4}$$

$$0 \leq E(t) \leq E_{MAX}, \tag{4.5}$$

where the notation is defined as:

$x(t)$ = fish population mass at time t,

$G(x)$ = net growth function,

$h(t)$ = harvest (catch) rate,

$E(t)$ = fishing effort,

q = catchability coefficient,

p = sale price of fish,

c = cost of effort,

$\pi(x(t),E(t))$ = profit.

The various parameters are assumed to be known.

1. Growth

The natural growth function is also assumed to satisfy the following:

$$G(0) = G(K) = 0, \qquad G(x) > 0 \text{ when } 0 < x \leq K \tag{4.6}$$

where K denotes the environmental carrying capacity (natural biomass equilibrium). This can be deduced by assuming that the both the birth rate (b) and the natural mortality rate (m) are proportional to the population mass (x) at each stock level. This is a reasonable assumption. Also assuming, for the moment, that there is no harvesting ($h(t)=0$), then the production function in Equation 4.1 can be rewritten as

$$\frac{dx}{dt} = G(x) - 0 = (b - m) \cdot x = r \cdot x, \tag{4.7}$$

where r denotes the net proportional growth rate. Solving this differential equation yields

$$\int \frac{1}{x} dx = \int r\, dt$$

$$\ln x = r \cdot t$$

$$e^{\ln x} = e^{rt}$$

$$x(t) = e^{rt} \qquad (4.8)$$

Thus, over time the biomass level would grow to an infinite size, if the net proportional growth rate was positive ($r > 0$), or approach zero if it was negative ($r < 0$). Clearly, this is not the case; many biological factors inhibit infinite movement. As stock levels increase, environmental limitations force the rate of growth to decline. Consequently, Equation 4.8 can be altered

$$\frac{dx}{dt} = r(x) \cdot x \qquad where \qquad r(x) = \frac{G(x)}{x} \qquad (4.9)$$

to reflect that the intrinsic growth rate is some decreasing function of the population mass. (Clark, 1990; Clark, 1985; Gulland, 1977)

For a specific example, Clark (1990) uses the logistics population equation developed by P.F. Verhulst in 1838, when $r(x) = r\ (1 - x/K)$, Equation 4.9 becomes

$$\frac{dx}{dt} = r \cdot x \cdot (1 - \frac{x}{K}) = G(x). \qquad (4.10)$$

Remembering the assumption of zero harvest, explicitly solving this differential equation by separating variables yields:

$$\frac{dx}{dt} = \frac{1}{K} \cdot r \cdot x \cdot (K - x)$$

$$\frac{dx}{x \cdot (K - x)} = \frac{r}{K} dt$$

$$(\frac{1}{x} + \frac{1}{(K - x)}) dx = r \cdot dt$$

so that, by integration,

$$\int (\frac{1}{x} + \frac{1}{(K - x)}) dx = \int r \cdot dt$$

$$\int \frac{1}{x} dx + \int \frac{1}{(K - x)} dx = rt$$

$$[\ln x - \ln (K - x)] \Big|_{x_0}^{x} = rt \qquad where\ x_0 = x(0)$$

$$[\ln x - \ln(K - x)] - [\ln x_0 - \ln(K - x_0)] = rt \qquad where\ x_0 = x(0)$$

$$\ln \frac{x}{(K - x)} = rt + \ln \frac{x_0}{(K - x_0)}$$

The solution may be rewritten in the form

$$e^{\ln \frac{x}{(K - x)}} = e^{(rt + \ln \frac{x_0}{(K - x_0)})}$$

$$\frac{x}{(K - x)} = e^{rt} \frac{x_0}{(K - x_0)} \qquad letting\ \alpha = \frac{(K - x_0)}{x_0}$$

$$\frac{K}{x} = \alpha \cdot e^{-rt} + 1$$

$$x = \frac{K}{\alpha \cdot e^{-rt} + 1} \tag{4.11}$$

Equation 4.11 determined the limit condition such that K is the saturation level

$$\lim_{t \to \infty} x(t) = K \quad \text{when} \quad r > 0. \tag{4.12}$$

The implication is that if the stock population is greater than zero but less than the carrying capacity ($0<x<K$), the change in stock with respect to time is positive ($dx/dt>0$) until a growth balance ($b=m$) is reached. (Clark, 1990; Clark, 1985; Gulland, 1977)

The relationship between the rate of growth and the stock level is depicted in Figures 4.1 and 4.2.

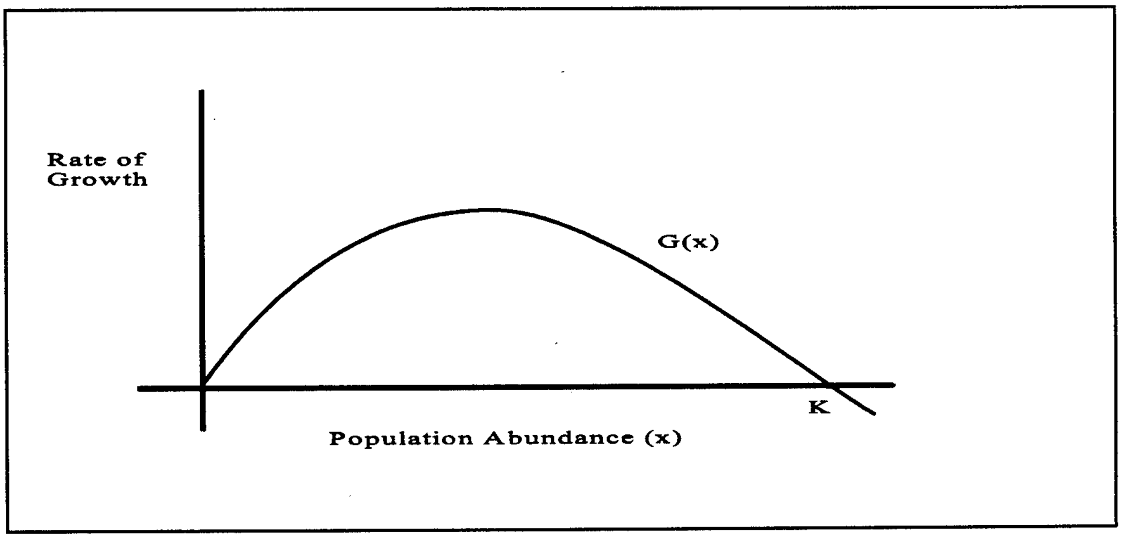


Figure 4.1: Relationship between the growth function and population. From Clark (1990).

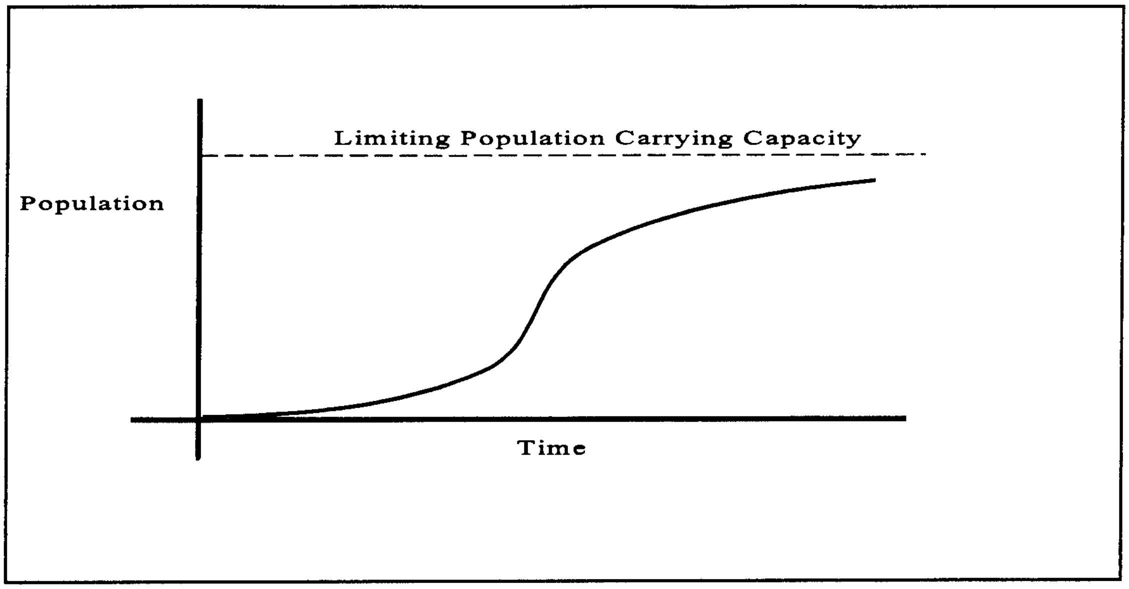


Figure 4.2: Growth of a fish population in a limiting environment. After Gulland (1977).

2. Harvesting

Equation 4.1 states that the biomass of a renewable resource will tend to increase ($dx/dt > 0$) whenever the natural growth rate exceeds the harvesting capacity. Of course, the reverse is also true. If, however, the growth rate is matched by the rate of removal, the stock population maintains a sustainable level. In other words, there corresponds a catch rate that balances new growth at each stock level and therefore establishes an equilibrium position. When this equivalency occurs, a sustainable yield can be captured while preserving a fixed population level. However, this is not necessarily the maximum yield.

By subjecting the stock population to fishing and, for simplicity, holding the harvesting capacity to a constant ($h(t) = h$), Equation 4.10 can be written as

$$\frac{dx}{dt} = G(x) - h(t) = r \cdot x \cdot (1 - \frac{x}{K}) - h. \tag{4.13}$$

If the removal rate exceeds the maximum rate of growth ($h > \max G(x)$), as it does in Figure 4.3, the population level will approach zero over time for any initial population.

If, on the other hand, the harvest rate is less than the maximum growth rate ($0 < h < \max G(x)$), as it is in Figure 4.4, then there exists two equilibrium positions, x_1 and x_2. If the initial mass lies between these points ($x_1 < x(0) < x_2$), then the stock level will converge to the x_2 equilibrium point as the rate of new growth out paces the rate of fishing. Likewise, if the initial population is greater than x_2, the biomass will converge to the x_2 where the rates of new growth and removal balance. Lastly, if the initial stock is less than x_1, then the population will approach zero as harvesting continues to deplete the stock. (Clark, 1990; Clark, 1985)

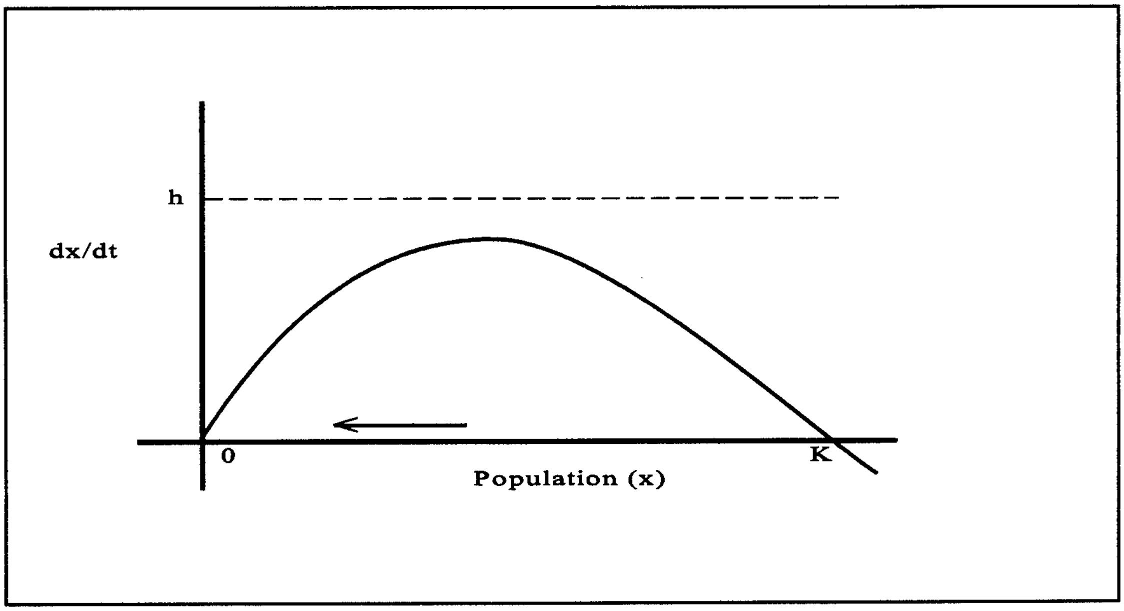


Figure 4.3: Logistics model with constant harvest rate $h > \max G(x)$. After Clark (1990).

When maximum growth and removal equate ($h = \max G(x)$), there exists a lone equilibrium, as depicted in Figure 4.5. If peak growth occurs at 50 percent of the environmental carrying capacity, then $x_3 = K/2$. Initial stock levels greater than this value ($x(0) > x_3$) will converge to this equilibrium point. But initial masses less than this quantity will approach zero as the constant level of harvest depletes the resource. (Clark, 1990)

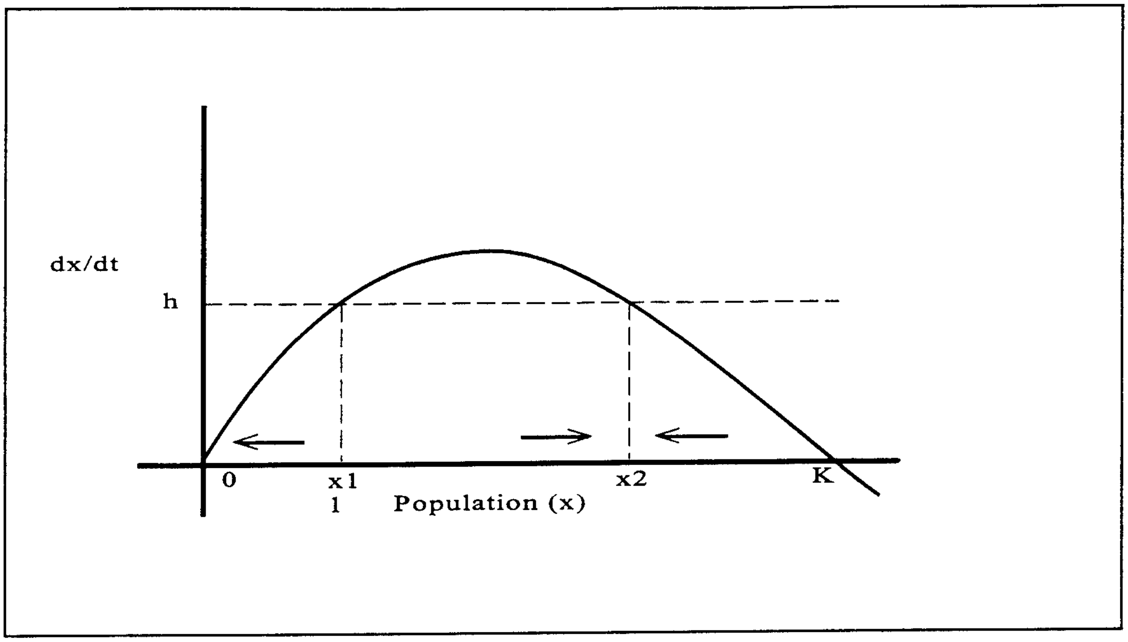


Figure 4.4: Logistics model with constant harvest rate h < max G(x). After Clark (1990).

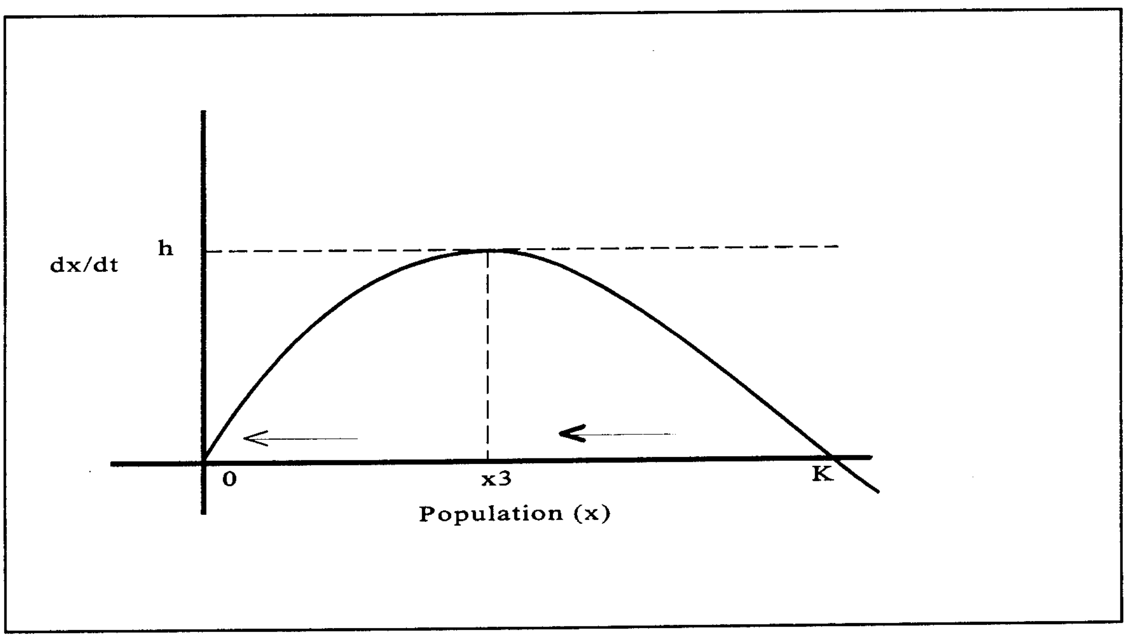


Figure 4.5: Logistics model with constant harvest rate h = max G(x).

3. Fishing Effort

The level of effort within a fishery can be measured or defined in a variety of ways (e.g., the total number of vessels per day, the volume of seawater screened by fishing gear per hour, etc.). Regardless of the measure, this model assumes the catch-per-unit-effort is proportional to the population level, as indicated in Equation 4.2. Rewriting Equation 4.1 to reflect this proportionality yields

$$\frac{dx}{dt} = r \cdot x \cdot \left(1 - \frac{x}{K}\right) - q \cdot E(t) \cdot x(t). \tag{4.14}$$

With a fixed level of effort and a removal rate that does not exceed the net proportional growth rate (qE < r), one unique nonzero equilibrium exists at

$$\frac{dx}{dt} = r \cdot x \cdot \left(1 - \frac{x}{K}\right) - q \cdot E(t) \cdot x(t) = 0$$

$$x_4 = K\left(1 - \frac{qE}{r}\right). \tag{4.15}$$

Furthermore, any initial stock level converges to this equilibrium, as seen in Figure 4.6, given the aforementioned assumption. Corresponding to this level of effort, the equilibrium harvest, or sustainable yield (Y), is given by

$$Y(E) = h = q \cdot x_4 = q \cdot E \cdot K \cdot \left(1 - \frac{qE}{r}\right). \tag{4.16}$$

However, if removal surpasses new growth (qE > r), then the stock level is driven to zero overtime. (Clark, 1990; Clark, 1985; Gulland, 1977)

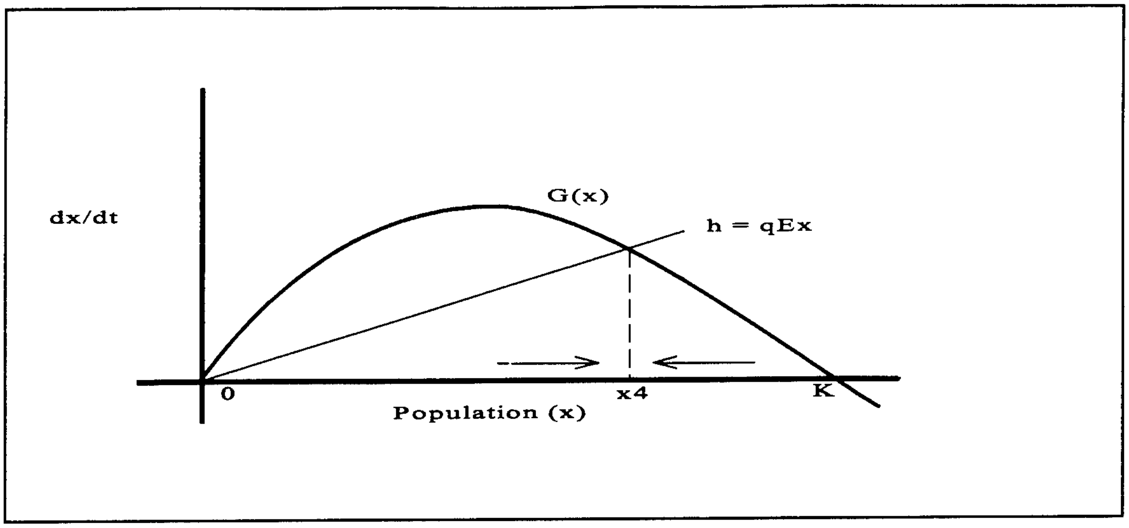


Figure 4.6: Logistics model with constant rate of effort (E). After Clark (1990).

B. BASIC ECONOMIC MODEL

The basic economic model is represented essentially by Equation 4.4. According to Clark (1980), the bionomic equilibrium[6] in an open-access fishery is the population mass at which a fishery's profit becomes zero. Although, as noted in Chapter II, some fisheries are experiencing a negative profit. Nevertheless, assuming that the cost per unit of effort and the price of fish are constant, the equilibrium biomass level can be determined by setting the basic net revenue expression to zero and solving for x(t).

$$\bar{x} = \frac{c}{pq} \tag{4.17}$$

Equation 4.17 suggests, as expected, that lower cost to price ratios result in relatively more severe stock depletions and subsequently lower stock levels. Hence, to the achieve the MEY, the population mass should be adjusted from the initial biomass (x(0)) to the optimal biomass (x^*) as swiftly as possible by altering the fishing effort accordingly. (Clark, 1985)

---

[6] First used in *The economic theory of a common property resource: the fishery* by H.S. Gordon's (1954), the term bionomic equilibrium describes a level determined by both biological and economic parameters.

V. UNREGULATED FISHERY ECONOMICS

A. SOLE-OWNER EFFORT

If the utilization of a fish stock is carried out by a single economic unit, it is reasonable to assume that the sole-owner's goal is to maximize profits from the fishery. This is exceptionally convenient, since the chief interest in determining whether to modify the level of effort would then be the marginal yield. For instance, if the cost of a unit of effort, including the opportunity cost of investing in some other activity, is less than the marginal gain, then added effort would be economically desirable. This additional effort could come in a number of forms, including investment in new and faster trawlers, improved capturing equipment, more labor, etc. Similarly, if the cost of a unit of effort exceeds the marginal gain, then increasing the fishing magnitude would be undesirable.

A sole-owner would have the ability to control the level of effort within a particular fishery, but not to control the market price as with a monopolist. This distinction is important. Market competition typically betters social welfare, but uncontrolled competition for common resources does not. It is also assumed that the sole-owner is pursuing long-term profits and not seeking a quick depletion of the resource (cashing out). Given these assumptions, the long-term stock equilibrium giving the maximum net economic return is simply $x(t) = x^*$, where x^* is the unique maximum solution to first derviative of Equation 4.4. Under single ownership, the optimal harvest policy would be the effort that drives the initial stock population to x^* as quickly as possible. This rate can be expressed in terms of both effort, as in Equation 5.1, and harvesting, as in Equation 5.2,

$$E^*(t) = \begin{cases} E_{\max} & \text{if } x(t) > x^* \\ \dfrac{G(x^*)}{qx^*} & \text{if } x(t) = x^* \\ 0 & \text{if } x(t) < x^* \end{cases} \tag{5.1}$$

$$h^*(t) \begin{cases} h_{max} & if\ x(t) > x^* \\ G(x^*) & if\ x(t) = x^* \\ 0 & if\ x(t) < x^* \end{cases} \tag{5.2}$$

where E_{max} represents the maximum capacity available to the owner and h_{max} denotes the maximum achievable capture rate. Simply put, a profit maximizing sole-owner would harvest at the greatest rate achievable when the stock population is above the MEY level; and completely refrain from harvesting if the biomass is below this level. Once the stock reaches the point of MEY, it would be maintained by matching the removal and recruitment rates. (Clark, 1985)

B. OPEN-ACCESS EFFORT

1. Basic Economics

Very few fish stocks are exploited by a single enterprise; most are subject to open and uncontrolled access. A continuing theme throughout this text has been the grave consequences of this open-access exploitation. As noted in Chapter II, the tendency of a common property fishery, in the absence of any economic restraint on effort, is to become depleted and economically unprofitable. Operating as individuals, each user seeks to maximize the difference between revenues and costs. But because there are no constraints on the number of producers that can enter the fishery nor on the amount of capital and labor that can be injected, any true profit will attract additional speculators and/or greater effort. Consequently, over the long-run, the value of the catch will approach the cost of catching it.

A simple model of this uncontrolled exploitation is depicted by the Gordon-Schaefer parabolic yield-effort curve in Figure 5.1. Recalling from Chapter IV, each point

on the curve corresponds to the sustainable yield resulting from a given effort. Assuming a fixed price and a cost, constant and proportional to the level of effort expended, the total sustainable revenue and total cost functions can be represented by

$$TR = p \cdot Y(E) \tag{5.3}$$

$$TC = c \cdot E \tag{5.4}$$

Subsequently, the sustainable economic rent, or profit, function can be expressed as

$$\pi = TR - TC = p \cdot Y(E) - c \cdot E = pqEK \cdot (1 - \frac{qE}{r}) - cE \tag{5.5}$$

And similar to the determination of the bionomic stock equilibrium calculated in Equation 4.17, the equilibrium effort level in an open-access fishery can be solved by setting the profit function to zero. When all economic rent has been dissipated, the effort equilibrium can be expressed as

$$\pi = pqEK \cdot (1 - \frac{qE}{r}) - cE = 0$$

$$cE = pqEK \cdot (1 - \frac{qE}{r})$$

$$(1 - \frac{qE}{r}) = \frac{c}{pqK}$$

$$\overline{E} = \frac{r}{q} (1 - \frac{c}{pqK}) \tag{5.6}$$

If the biological elements are known, then the effort equilibrium becomes a function of the cost-price ratio. (Clark, 1990; Clark, 1985)

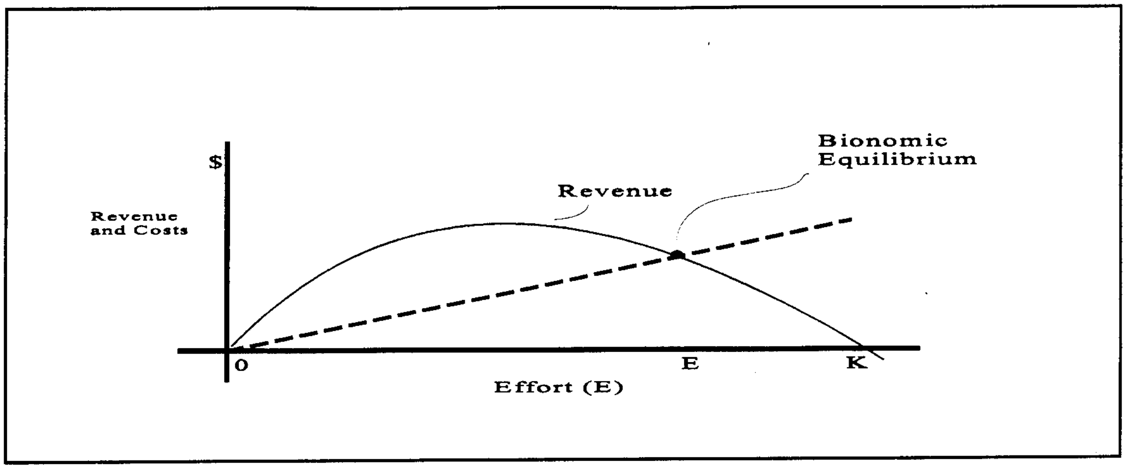


Figure 5.1: Bionomic equilibrium in an open-access fishery. From Clark (1985).

Thus far, the focus as has been on the more interesting low cost to price ratio, as displayed by curve TC_L in Figure 5.2, but this is not always the case. In fact, as with so-called *trash* fish, the fishing costs are sufficiently high compared to the stock's market value that the fishery is not exploited (TC_H). Equally conceivable is an effort equilibrium in which the resource is exploited but at a biomass below the point of MSY (TC_M). In this case, biological overfishing is avoided, but rents are still zero. Clearly, the more valuable the stock relative to the capture cost, the more intensively it will be depleted under open-access conditions. (Clark, 1990)

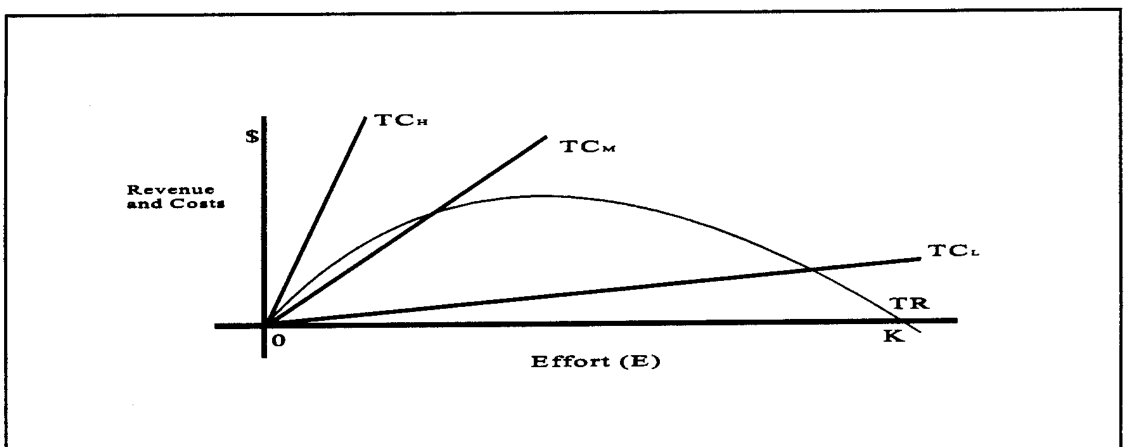


Figure 5.2: Equilibrium levels at different cost-price ratios. After Clark (1985).

VI. REGULATED FISHERY ECONOMICS

Previous chapters examined many features of open-access, common-property resources to explain the phenomena of biological and economic overexploitation. A model was presented to predict the utilization patterns of private resource owners, in an attempt to identify the attributes of optimal exploitation practices. One conclusion drawn from this analysis holds true for all fisheries: with free and open access exists and increasing product demand, a fishery will inevitably induce excessive amounts of labor and capital, eventually to the point of economic inefficiency. It seems clear that some system for regulating free and open-access is needed to avert the misuse of these resources.

However, if fishery management betters the social and economic well-being of its users, why do controls have to be imposed and enforced? Should not fishermen willfully adopt such restraints making the fishery self-regulating? This overlooks one important point: the decision to maximize economic yields must be made collectively. No individual user would limit his or her production rate unless *all* other users took the same measures. Since the level of effort exploiting an unregulated fish stock continues to grow until there is no longer an economic incentive for further expansion, lone restraint means *loss* of harvest not deferment. Furthermore, the development of a coalition, even if it could get full and honest participation, would not generate profits because of the fishery's open nature.

It has also been claimed that governments should not enhance the profits of select industries. However, those putting forth this argument not only fail to fully realize the considerable economic benefits accruing to society *as a whole*, but also the severity of the potential losses in the absence of fishery management. Some regulatory action is often needed to prevent economic disaster. Although there may be some powerful arguments against *too* much management, the problems resulting from inaction have been repeated throughout this text. The only comparison that needs to be made is between the outcomes

of particular actions, and that of inaction to see why management can be more effective in achieving both stock conservation and profit generation.

Unfortunately, the variety of controls traditionally applied to fisheries is impressive in number only. Overly zealous administrators have found ways to restrict virtually every facet of the fishery operations. Common are constraints affecting vessel type, dimensions, horsepower, and tonnage; equipment type, size, and construction; time and place of fishing; species, size, and amount of fish captured; and processing plant capacity. However, little if any economic analysis went into developing most of these methods of fishery management; all of which are prevalent today. Historically, management strategies have rarely considered their complete economic ramifications. Rather, they have emerged almost exclusively from a biological context. Although these techniques have occasionally proved successful for long-term conservation, they provide few, if any, economic advantages.

The list of the fishery management restrictions to be economically assessed is lengthy, but by no means exhaustive.

1. Citizenship restrictions: limiting access based on nationality.
2. Vessel and gear constraints: physical properties of vessels (dimensions, tonnage, horsepower, etc.) or of fishing equipment (type, size, number of nets, traps, etc.).
3. Time and place restrictions: seasonal or area closures.
4. Financial disincentives: taxes or royalties on catch or on fishing effort.
5. License limitations: licensing a restricted number of fishermen or vessels.
6. Total quotas: total allowable catch quantities by species and area.
7. Allocated quotas: catch quantities are allocated to individual fishing enterprises.

Other control measures include vessel ownership restrictions, trip limits, quality and handling restraints, and type-catch controls.

In addition to a fixed price and cost of unit effort, there are three principal assumptions underlying this attempt to gauge the economic implications of various management designs. For one, the resource will continue to be utilized under conditions of pure competition after implementing regulatory controls. In other words, the fish stock remains common-property, but not necessarily open-access if the number of producers is restrained. Secondly, the resource in question must largely lie within the jurisdiction of a single nation, which can therefore advance the same authority over all parties. And lastly, the primary objective of fishery management is to achieve the MEY. But since the main purpose is to discuss how regulation can affect efficiency in the production of effort, very little insight will be lost with this assumption.

A. MAGNUSON FISHERY CONSERVATION AND MANAGEMENT ACT

Throughout most of history, common-property fish stocks have been basically uncontrolled, with the exception of a few limits on size, area, and season. It was not until the mid to late 1960s that the U.S. fishing industry and the general public began to recognize the need for more *fishery management*. By this time large factory trawlers from Asia and Europe had begun regularly fishing off the North American coast, often with the intention of quickly depleting the resource before venturing on. With the enactment of the Magnuson Fishery Conservation and Management Act, the United States expanded its authority over fishery stocks from 12 to 200 miles offshore. Enthusiastically supported by the U.S. fishing industry, the legislation's purpose was to end the overutilization of fishery resources, which was chiefly blamed on foreign fleets, and to encourage U.S. producers to expand operations. (Sissenwine and Rosenberg, 1993)

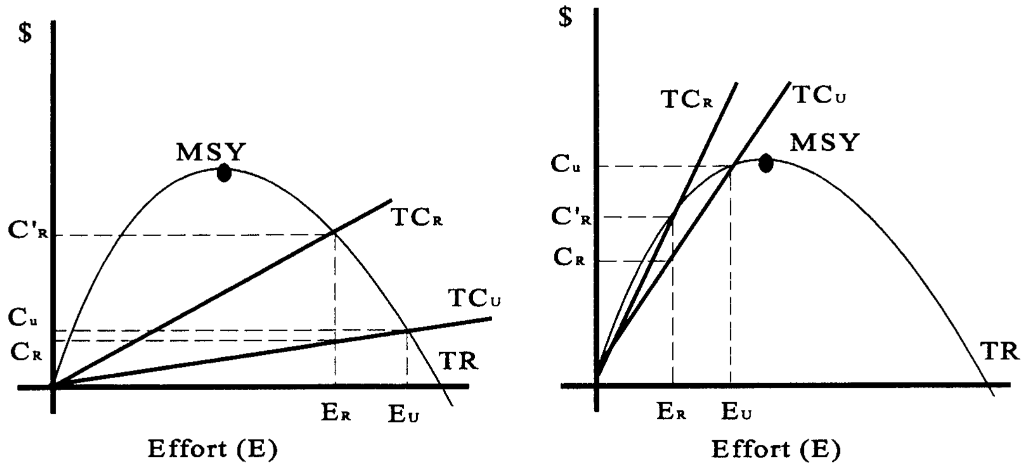
Ironically however, by extending the Exclusive Economic Zone (EEZ), the U.S. "traded overfishing by once-dominant foreign fleets for domestic overcapitalization throughout the country and overfishing in some regions." (Swartz and Sissenwine, 1993) Other than perhaps the makeup (nationality) of the participants involved, recent studies by scientists at the National Marine Fisheries Service indicate that relatively little change in

the utilization of coastal U.S. fish stocks has occurred in the post Magnuson Act era. Although, the legislation failed to account for the economic incentives of the U.S. fleet and thus was largely inadequate in ending the chronic overutilization problems, it did serve to put 90 percent of the value of U.S. exploited fisheries in the hands of a single jurisdiction. This consummate control continues to play a crucial role in the enactment and enforcement of other regulatory measures. (MacKenzie, 1987)

B. PHYSICAL CONTROLS

The oldest forms of management are directed exclusively towards biological conservation of fish stocks, by employing physical constraints that limit the time and place of fishing and/or the type of gear that can be used. These regulations serve to increase the costs of producing effort or, at the very least, to prevent a reduction in fishing costs. Time and gear restrictions do not result in an optimal use of fishing effort, but rather a regulated inefficiency. Prohibiting technologically efficient gear or causing common-property users to fish at accelerated rates over a shortened seasons only serves to make fishing a more costly endeavor for the fishermen, not a profitable one.

Simply put, the affect of placing constraints on the way inputs can be used in open-access fishery operations is to cause the cost curve to shift upwards, intersecting the revenue function at a lower level of effort. However, producing this regulated effort level in a shorter time period or with limited equipment causes the unit cost of its production to raise from C_R to C'_R , as illustrated in Figure 6.1. Where the new total cost curve intersects the revenue curve, the fishery converges to a regulated bionomic equilibrium in which net economic yield again approaches zero. The end result is that the open-access equilibrium level of effort is reduced, but only through the indirect effect of greater total costs. (Bohnsack, 1993; Anderson, 1977)



i) Low Cost-Price Ratio

ii) High Cost-Price Ratio

Figure 6.1: Physical controls reduce the open-access level of effort by increasing unit costs through forced inefficiencies. After Anderson (1977).

There are additional aspects to the problem of physical controls that should be noted. Prohibiting fishing in particular areas or during certain times of the year can simply cause common-property users to expand their effort in other areas and/or at different times, at a higher cost. This is especially true if the targeted stock is available throughout the year or over many regions. Likewise, there are no assurances that the excluded labor and capital will be shifted to some underutilized fishery, or into an altogether different segment of the economy. If the released labor and gear remains idle or is shifted into to an already overexploited market, then regulatory action could be counterproductive. Other considerations include the effect on consumption; if fresh fish is available for only short durations, more of the capture would have to be frozen for off-season use. All regulatory programs must constantly weigh such relative gains and loses to determine whether a net economic or social benefit would result. (Bell, 1978)

Another problem with equipment controls is that producers often uncover improvements to circumvent the regulations, given time to adjust. Consequently, total costs would fall and the effort level expand. Further controls would have to be continually enacted in order to maintain effort at specified levels. In summary, the imposed inefficiencies *may* increase the economy's well-being, but this does not often happen. When it does occur, the economy is still not operating efficiently. Further gains in social welfare are always possible if proper regulations remove, vice inflict, inefficiencies. It is also obvious that escalating the expense of fishing can, in some cases, be an effective means of increasing the sustainable yield. In principle, the cost function could be adjusted to meet the revenue curve at the MSY, as depicted by TC_{MSY} in Figure 6.2. But again, this is a haphazard technique that aims to achieve a purely biologically oriented goal by deliberately instituting economic inefficiency. Thus, it is futile to try to fulfil any long-term economic objective, such as profit generation, via physical controls.

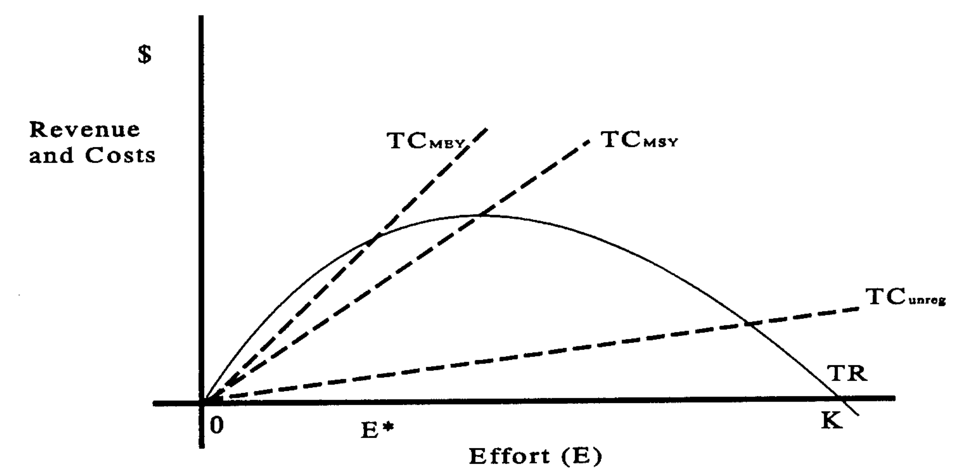


Figure 6.2: Adjustment in the cost curve of a regulated fishery. After Clark (1990).

C. TAXES AND ROYALTIES

Financial disincentives have long been advanced as the simplest and most direct method of capturing rent from common fishery resources. However, the employment of taxes on a per catch basis has been minimal at best. There is little doubt that landings taxes offer greater promise as a regulatory device than the physical constraints previously discussed. Clearly they also affect each user's incentive to exploit fishery resources, but they do so without forcing operators to adopt inefficient means. Simply put, fewer fishermen would be willing to participate in the market. The more efficient producers would remain and they would be more cognizant of their production levels. (Clark, 1990; Anderson, 1977)

Since the profit-maximizing producers must pay this tax, they would use new total cost curves in determining the desired effort level. This representation is similar to the cost increase depicted in Figure 6.1. To see the effect of a catch tax analytically, adjust the basic model's profit equation to reflect a tax of τ,

$$\pi(x,E,\tau) = (p-\tau)h(t) - c(E)\cdot E(t) = [(p-\tau)q\cdot x(t) - c(E)]E(t) \qquad (6.1)$$

Maximization of the new rent function implies that

$$\frac{d\pi}{dE} = (p-\tau)\cdot q\cdot x(t) - c(E) = 0$$

$$c'(E) = (p-\tau)\cdot q\cdot x(t) \qquad (6.2)$$

Thus, effort is clearly a decreasing function of the tax rate

$$\frac{dE}{d\tau} < 0 \qquad (6.3)$$

If the tax exceeds the sale price ($\tau \geq p$), effort would cease. (Clark, 1990)

The reasoning behind this is simple. Profit minded producers compare their private gains per unit of effort with their marginal cost of this effort. They completely neglect the effect their effort has on the revenue of other operators in the fishery. The tax reduces the revenues received by an individual operator, potentially making them more comparable to the marginal revenue of effort for the entire fishery. This modified marginal revenue is compared to the marginal cost of effort when making production decisions. As with physical controls, the perceived cost curve in this case could theoretically be adjusted to any desired effort level. The total cost curve in the presence of the optimal tax is reflected by TC_{MEY} in Figure 6.2. In this case, the bionomic equilibrium coincides with the point of maximum fishery profits. Of course, all of this profit would accrue to the tax-collecting authority. (Clark, 1985; Anderson, 1977)

The fact that the users still receive zero rent makes the imposition of catch taxes extremely unpopular with the fishing industry. The common misconception is that the enterprise would be *profitable* without the duty. Not surprisingly, regulation by taxation has seldom received serious consideration. However, there is one chief difficulty associated with the taxation strategy. Calculating of the optimal duty would require the central authority to know the operating cost structure of each producer, as well as the biological attributes of the fish population. A very demanding task in a variable world. The optimal tax would have to be recomputed and relegislated on a continual basis. (Clark, 1990; Anderson, 1977)

In conclusion, while taxation holds little appeal to the commercial fisherman, it does affect the level of effort without adversely affecting efficiency. When taxes are used properly, resource rents can be captured for the benefit of the taxing authority and subsequently society; not lost because users were forced to use inefficient methods. Although economic rents can be optimized, the question remains whether economic efficiency can be achieved without taking the profits of the individual fisherman.

D. LIMITED ENTRY VIA VESSEL/OWNER LICENSES

Like with physical constraints and landing taxes, vessel licenses also increase costs to the individual fisherman. And in fact, most nations license one or a combination of inputs to their fisheries, including fishermen, vessels, tonnage of vessels, units of gear, etc. However, these user fees are typically nominal. Licenses are often granted to *all* citizens who apply. Licensing is seldom used as a management tool in regulating a fishery's capacity. Such cases represent an obvious movement away from open-access fishing and towards exclusive property rights. As with the control measures noted throughout this chapter, the concept of displaced resources remains a chief concern. However, limited entry systems differ sharply from the preceding controls in that producers are pushed out of the fishery by an outside authority vice existing on their own accord. (Clark, 1985; Anderson, 1977)

A few in the fishing industry, and a few authors continue to argue that limiting access to a fishery for fishermen, vessels, or both, would end the chronic problems of overcapitalization. They base their position on the errant belief that restricting the fleet size would generate the optimum harvest. However, simply restricting access to a finite number of entrants fails completely to consider the economic incentives that dominate common-property exploitation. While the level of effort would initially be reduced, profit minded fishermen would alter their operations in the long run to reflect the increase in stock productivity and the potential to gain added revenues. Producers would still find it profitable to invest in larger ships, additional and more efficient equipment, etc. (Clark, 1990; Anderson, 1977)

It has also been asserted that the capital *removed* from each licensee would inhibit subsequent expansion to some degree. This is especially true if license fees could be periodically adjusted to reflect the expected rents of each operator. Under such conditions, the fees would be essentially the same as taxes on effort. This could effectively extract economic rents from a fishery. However, it is extremely improbable that license fees

would be able withdraw *all* profits from a particular fishery; hence, the motivation to expand production would persist. Unless license holders are somehow precluded from increasing their inputs, license limitations alone are unlikely to ensure economic efficiency. (Clark, 1980)

Fishery managers typically try to impede the spiraling effort levels within limited access programs by incorporating physical constraints. Gear restrictions and seasonal closures are frequently enforced to prevent overfishing. Some economists maintain that such a system can be effective, if controls are sufficiently limiting, but many believe that constraints on any one component of effort are eventually offset by expanded effort in other areas. The predictable outcome would be a never ending body of regulations. In fact, the only difference between physical controls in conjunction with limited entry and physical controls in general is that there is a smaller operator population. Over the long run, limited entry and physical controls would only reduce fishing effort if the controls increase production costs by reducing efficiency. (Clark, 1990; Anderson, 1977)

The few attempts at limited entry programs appear to bear this out. Fishery managers constantly battle common-property users; effort constraints are continually being implemented and subsequently circumvented. For example, in the late 1960s the Canadian government introduced a licensing system to limit the number of vessels in its Pacific Coast salmon fleet. Total capacity increased shortly after implementing the fleet reduction program as fishermen replaced smaller older frigates with large trawlers. Administrators responded by limiting the total tonnage of fishing vessels. Producers then acquired more efficient gear and equipment. The game continues today.

In another example, in the 1970s the Peruvian government limited access to reduce the excess capacity of its anchovy fleet. However, harvesting increased when operators introduced echo-sounders, fish pumps for more quickly transferring fish from the nets to the hold, and power blocks for improved net handling. Increased effort in response to new controls seems to be a common trait of biologically oriented measures that disregard the common resource problem in basic fishery economics. (Clark, 1990; Anderson, 1977)

E. TOTAL QUOTA SYSTEM

In many respects, total unallocated catch quotas act like seasonal closures, at least over the short-term. The length and timing of seasonal restrictions are commonly based on a regulatory agency's view of the amount of fish that *should* be harvested during a given period. In other words, closures are simply an indirect means of instituting a total quota. Unfortunately, quota systems are not exempt from the problems facing seasonal policies. Fish populations can fluctuate for reasons not connected with the level of fishing. The total allowable catch would have to be regularly adjusted to maintain the mortality rate at the desired level. Usually, an *average annual* quota is established. In a year when resources are scarce, stock abundance could fall to undesirably low levels. Similarly, total quotas introduce an incentive for more and bigger vessels to race for the limited amount of fish, until fishing is no longer a profitable investment. (Gulland, 1977)

As noted, any success in reducing fishing costs or expanding revenues attracts additional effort. This would lead to shorter seasons, as quotas are met more rapidly, and increasingly inefficient operations by common-property users. Producers would keep striving to reduce the amount of time it takes to produce a unit of effort. This would increase unit costs. This race against time would continue until the total cost of the effort required to catch the quota equals the total revenue. Theoretically the *proper* catch would be taken in each period, but the expense of doing so is certainly not minimized. It is unlikely that any long-term economic objectives could be fulfilled by using of a single unallocated quota. (Anderson, 1977; Gulland, 1977)

Mathematically, the total catch quota system is relatively simple. In an overexploited fishery, the quota must be set at an artificially low level to permit stock rehabilitation. Eventually, the fish population would recover to the maximum economic yield or maximum sustainable yield, depending on the regulatory agency's objective. The total allowable harvest would then be raised to match that catch. Returning to the basic fishery model presented in Chapter IV, the model can be modified by adding a constraint

$$\sum_i Y_{ij} \leq Q_i \qquad (j \geq 0) \tag{6.4}$$

$$Y_{ij} = \int_{jT}^{(j+1)T} h_i^{\max}(t)\ dt \tag{6.5}$$

where Q_j represents the total allowable catch for period jand Y $_{ij}$denotes the *i*th fisherman's total harvest in that period. The individual producers' problem is then to maximize their profit such that for N equivalent fishermen

$$E_i(t) = \begin{cases} E_i^{\max} & if \sum_i Y_{ij} < Q_i \\ 0 & otherwise \end{cases} \tag{6.6}$$

In a perfect world with perfect information, the total allowable catch scheme could be used to prevent the stock biomass from being harvested below the point of MEY (or MSY). However, without further limitations on effort and entry, the fishery would become overcapitalized, tending towards an equilibrium where returns equal costs. The effect would be to replace overfishing with overcapacity. Since producers disregard their effect on the fish population and on the time of closure, this problem cannot be treated as an optimal control exercise. The commercial fisherman's only choice is to determine the level of capitalization. (Clark, 1980)

The competitive Nash solution can be determined via response functions. Figure 6.3 displays the reaction curves ϕ_i for two equivalent producers. The Nash solution is at point Q. For more than two equivalent producers (N > 2), response surfaces can be calculated as follows:

$$E_i^{\max} = \phi(\sum_{i \neq i} E_j^{\max}) \tag{6.7}$$

The Nash solution E_N satisfies the following:

$$\lim_{N \to \infty} NE_N \to E^{\infty} \tag{6.8}$$

where E^{∞} is the amount of total capacity that inhibits added effort and further entry into the fishery. (Clark, 1980)

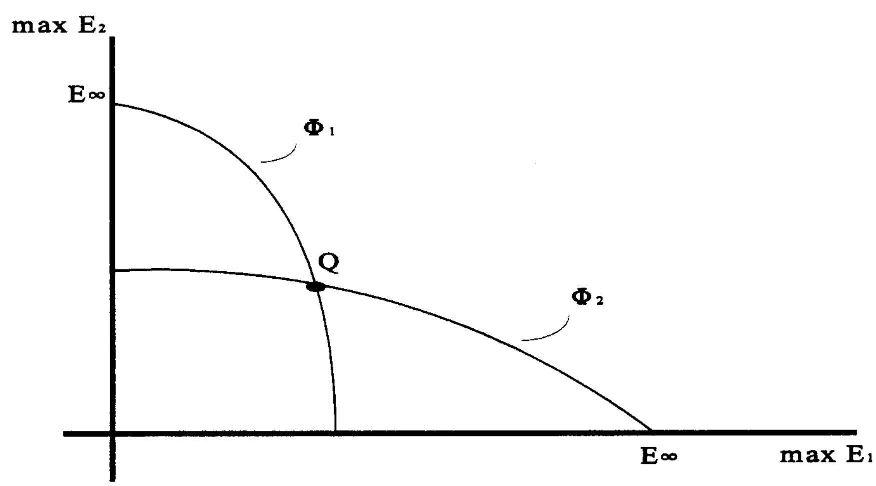


Figure 6.3: Response functions for a total quota system. The Nash solution for two producers is at point Q. From Clark (1980).

A combined limited-entry, total allowable catch program could generate positive profits, as with the British Columbia salmon fishery. However, equilibrium is at a suboptimal level with profits approaching zero as the number of producers increases.

Unquestionably, a classic stand-alone, total catch quota system would simply promote biological aspirations. It would not preserve profits or encourage efficiency. (Clark, 1990; Clark, 1980)

F. ALLOCATED QUOTA SYSTEM

An allocated quota can also control removal rates. While many of the biological obstacles persist, the prospects for economic efficiency are much greater with this strategy. The unallocated approach forces producers to compete for a share of the total harvest. Allocated quotas allow common resource users who own a personal quota to satisfy the quota at an efficient pace. With individual quotas, vessel operators are free to take their share whenever and however they prefer. The drive to reduce expenses and maximize profits would lead to orderly harvesting practices. Likewise, decisions to the adopt technological advancements would not be hastily influenced by the decisions of other operators nor inhibited by physical constraints. These decisions would depend on the ability to maximize long-term economic rents. Of course, an allotted quota scheme must be accompanied by some form of limited entry, either by restricting entry or by limiting the total number of allocated quotas. Without restricting the participants or total quotas, individual quotas would act like total catch quotas; serving absolutely *no* economic purpose. (Clark, 1985)

The impact of an allocated catch quota can be modeled by replacing Equation 6.4 with the constraint

$$Y_{ii} \leq Q_i \qquad (i = 1, 2, ..., N; j \geq 0) \tag{6.9}$$

where N (fixed) denotes the total number of allowances to be allocated. Therefore, the individual producer now faces the *constrained optimization* problem

$$\max \ \pi_i(x, E_i) = pqxE_i - c_iE_i \tag{6.10}$$

subject to Equation 6.9. The result of an individual catch quota is plainly evident. Each producer's capacity level (E^{max}) is essentially independent of optimal capacity of other common-property users, such that

$$E_i(t) = \begin{cases} E_i^* & \textit{if } Y_{ij} < Q_{ij} \\ 0 & \textit{otherwise} \end{cases} \tag{6.11}$$

The Nash solution for two producers can be represented by using response functions as illustrated in Figure 6.4. (Clark, 1980)

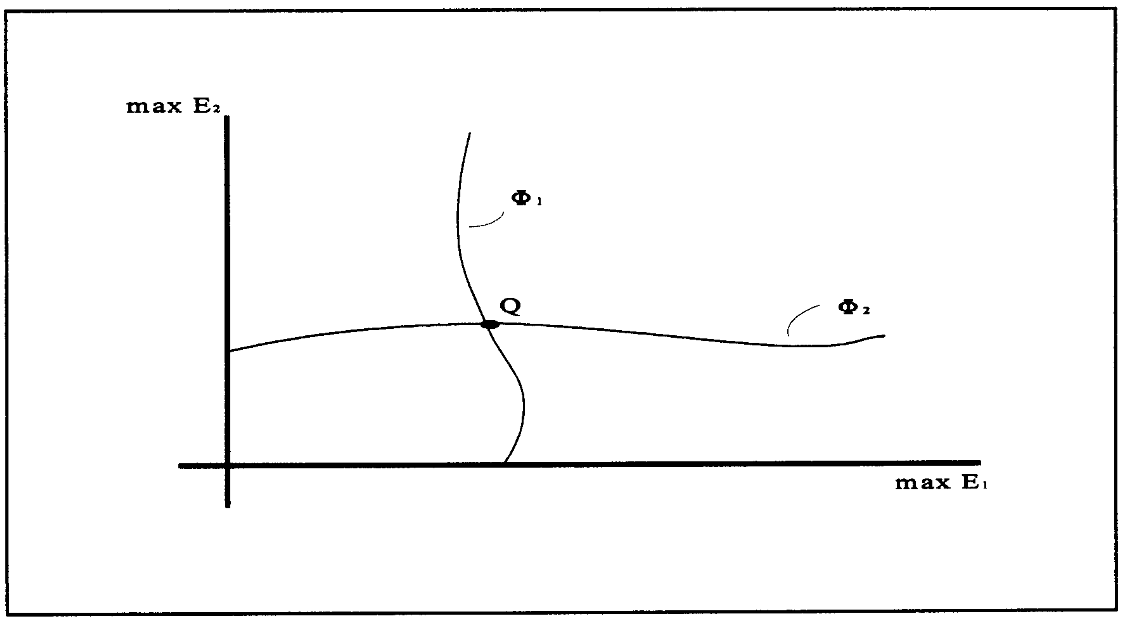


Figure 6.4: Response functions for allocated quota system. The Nash solution for two producers is at point Q. From Clark (1980).

Furthermore, individual quotas, like licenses, may or may not be transferable. Transferable allowances are more appealing from an economic standpoint. Some operators are more efficient than others. Quotas would be more valuable to more efficient

operators. These operators would outbid others for the right to harvest. Correspondingly, less efficient producers would be induced to exit the fishery. They could capitalize on their departure by selling their catch quotas. New fishermen would only be drawn to the fishery if they were more efficient than existing producers. Since economic self-interest would tend to prevail, a transferable allocated quota program would optimize efficiency for existing ships and the introduction of new vessels. (Clark, 1990)

In some sense, transferable allocated quotas are equivalent to catch taxes. This equivalence can be seen by rewriting the profit function in Equation 6.10 in terms of the stock population and the yield harvested.

$$\max\ \pi_i(x, Y_i) = pY_i - c_i \frac{Y_i}{qx} \tag{6.12}$$

An individual fisherman would profit from purchasing additional quotas if and only if the marginal gain in net revenue from the added capacity exceeded the cost. Letting m denote the cost of quotas, a producer would acquire more quotas as long as

$$\frac{\delta \pi_i}{\delta Y_i}(x, Q_i) > m \tag{6.13}$$

Conversely, an owner would market quotas when

$$\frac{\delta \pi_i}{\delta Y_i}(x, Q_i) < m \tag{6.14}$$

Thus, the individual user's demand function for quotas, $D_i = D_i(m, x)$, is:

$$\frac{\delta \pi_i}{\delta Y_i}(x, Q_i) = m \tag{6.15}$$

Explicitly, this produces

$$c_i'\left(\frac{D_i}{qx}\right) = (p - m)qx \tag{6.16}$$

from which it follows that

$$\frac{\delta D_i}{\delta m} < 0 \tag{6.17}$$

and

$$\frac{\delta D_i}{\delta x} \geq 0 \tag{6.18}$$

Likewise, it follows that

$$\frac{\delta m}{\delta x} = \frac{-(\delta D/\delta x)}{(\delta D/\delta m)} \geq 0 \tag{6.19}$$

Stated non-analytically, the demand for quotas decreases as fishing costs increase and the fishing stock decreases. Higher population levels imply that quotas become more valuable as the costs of capture decline. (Clark, 1990)

The total demand for quotas can be expressed as a function of the stock population and the price of a quota:

$$D(x,m) = \sum_{i=1}^{N} D_i(x,m) \tag{6.20}$$

The market-clearing price for quotas can then be determined from of the supply-demand equilibrium condition:

$$D(x,m) = Q \tag{6.21}$$

When quantity of quotas supplied and demanded are equal, i.e., the quota market has been *cleared*, then $Y_i = Q_i = D_i$ and Equation 6.16 becomes

$$c_i'(E_i) = (p - m)qx \tag{6.22}$$

Comparing Equation 6.22 and Equation 6.2, the equivalence of catch taxes and catch quotas is readily obvious.

$$c_i'(E_i) = (p - m)qx = (p - \tau)qx \tag{6.23}$$

A landings tax of τ has the same impact on the fishing effort as a transferable quota with a price of m. However, a tax is a direct expense for producers. It actually reduces the price received for their catch. A transferable quota represents an *opportunity* cost to producers. They could have sold their individual rights. A transferable allocated quota system can reduce the cost to the operators if the quotas are initially distributed to the operators. If the operators are required to purchase the quotas from the regulatory agency, the operators loses will be the same under the quota and tax systems. In theory, a regulatory authority could set the total supply of allocated quotas at the point of MEY. This would generate the quota price that maximizes profits and economic efficiency. (Clark, 1990; Clark, 1985)

VII. CONCLUSION

Many economists and marine biologists agree that managing the world's fisheries is becoming increasingly critical. The imbalance is growing between the capacity of the world's fishing fleets and the availability of common-property fishery resources. The development and introduction of long-range fishing fleets and sweeping improvements in fishing techniques, processing, and marketing have alarmingly increased the worldwide harvest. This document has presented the theoretical framework surrounding common-property renewable fishery resources and analytically examined specific regulations for curbing today's predominate inefficiencies. Although drafted as no more than an elementary analysis, the results still appear to be rather significant.

The fundamental reason why fisheries need to be managed is their common-property nature. This makes the fishing industry much harder to govern than other industries. It lacks the property-right delineations common in other enterprises. A general theme that has carried through most fishery management endeavors is an inordinate emphasis on controlling fishing effort by means that preserve the resource's common-property nature. In reviewing the management schemes in Chapter VI, only one regulatory measure, catch taxes, essentially dissuades using excessive amounts of capital and labor and protects the resource from overexploitation while allowing producers maximum freedom to function in a free enterprise fashion. Unfortunately, the proper use of such taxes has long been opposed by the politically powerful fishing industry. On the whole, they favor constraints that permit them free access to the fishery and can be easily sidestepped, such as equipment constraints. In other words, they favor those measures that offer *no* effective long-term solution.

To quell the voices of the environmentalists, exploiters of common-property fishery resources have pushed for legislation they find most beneficial. For obvious reasons, individual fishermen oppose landings taxes. The conventional methods of fishery

management, such as total catch quotas, gear restrictions, seasonal and area closures, etc., appear to address biological concerns and are the *least* disdained by the fishing industry. However, token efforts of this kind have no economic basis and completely bypass property-rights, the heart of the problem. These approaches inevitably breed economic distortions which induce further increases in capacity and render control of the resources progressively more difficult. Unfortunately, most fishery controls are passed only with the fishing industry's approval. They are yet to advocate restrictions that *exclude* fishermen from a fishery, even recognizing the overcapitalization and overfishing attributable to the common-property nature of the resource. Restricted access is particularly controversial because once producers exit, additional profit accrues to the survivors.

It is readily apparent from the analysis in Chapter V that the incentives to dissipate economic rents under competitive conditions cannot be overcome by the conventionally accepted control methods. These regulations fail to achieve economically optimal exploitation. In fact, only two techniques, taxes on catch and a combination of limited-entry and allocated quotas, appear to offer any promise of effectively thwarting this inducement. Owing to political opposition to taxation, common-property users may be compelled to affix rights (or proxies for rights) to fishery resources. Outside sole ownership, transferable allocated quotas are most capable of achieving the optimal allocation of effort. These quotas bestow resource rights to the quota holder. Sacrificing free and open access to fishery resources may be a necessary evil to efficiently use capital and labor, and deliver products to the consumer at the lowest price possible.

The future of commercial fishing lies in its ability to live within its resource boundaries. The fishing industry can achieve this goal using allocated quotas if fishermen can embrace the concept of sustainability; realizing that they *own* a valuable renewable resource. The use of allocated catch quotas will provide managers with a sufficient array of tools to directly tackle most of the current problems, but more emphasis needs to be

placed on controlling effort before overcapitalization occurs. Proposals to reduce the catch after stocks have become vulnerable to fishing pressure are often met with strong resistance. Most producers cannot endure even a short-term harvest reduction. An allocated quota approach should therefore prevent excess effort, vice simply restoring depleted fisheries. In this respect, fishery management and development should be considered as interacting aspects of the same process. Individual catch quotas are a relatively new concept for fishery management. Thus, there is little data available concerning their consequences. However, they seem to offer the most practical hope for economic efficiency. As experience with carefully designed and managed quota programs grows, more fisheries will likely brought under this form of management.

LIST OF REFERENCES

Alden, R., "Commercial Fishing: Improving the Industry's Image," *Sea Technology*, vol. 35, January, 1994, pp. 37-38.

Anderson, L. G., *The Economics of Fisheries Management*, Baltimore: Johns Hopkins University Press, 1977.

Bell, F. W., *Food From the Sea: The Economics and Politics of Ocean Fisheries*, Boulder: Westview Press, 1978.

Christy, F. T., and A. D. Scott, *The Common Wealth in Ocean Fisheries: Some Problems of Growth and Economic Allocation*, Baltimore: Johns Hopkins University Press, 1965.

Clark, C. W., *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*, 2nd ed. New York: John Wiley & Sons, 1990.

---. *Bioeconomic Modelling and Fisheries Management*, New York: John Wiley & Sons, 1985.

---. "Restricted Access to Common-Property Fishery Resources: A Game-Theoretic Analysis." In *Dynamic Optimization and Mathematical Economics*. Ed. P. T. Liu. New York: Plenum Press, 1980, pp. 117-132.

Gulland, J. A., *The Management of Marine Fisheries*, Seattle: University of Washington Press, 1977.

Holmes, R., "Biologists Sort the Lessons of Fisheries Collapse," *Science*, vol. 264, May, 1994, pp. 1252-1253.

Ludwig, D., R. Hilborn, and C. Walters, "Uncertainty, Resource Exploitation, and Conservation: Lessons from History," *Science*, vol. 260, April, 1993, p. 17+.

MacKenzie, W. H., *The Evolution of United States Policy on Foreign Fishing Fees*, Charlottesville: The Michie Company, 1987.

McHugh, J. L., *Fishery Management*, New York: Springer-Verlag, 1984.

Sissenwine, M. P., and A. A. Rosenberg, "U.S. Fisheries: Status, Long-Term Potential Yields, and Stock Management Ideas," *Oceanus*, vol. 36, Summer, 1993, pp. 48-54.

Swartz, S. L., and M. P. Sissenwine, "Achieving Long Term Potential From U.S. Fisheries," *Sea Technology*, vol. 34, August, 1993, pp. 41-45.

BIBLIOGRAPHY

Alden, R., "Fisheries Policy: A New Beginning," *Sea Technology*, vol. 27, January, 1993, pp. 35-36.

Bohnsack, J. A., "Marine Reserves: They Enhance Fisheries, Reduce Conflict, and Protect Resources," *Oceanus*, vol. 36, Fall, 1993, pp. 63-71.

Clark, M. K., "Commercial Fishing Outlook Still Uncertain," *Sea Technology*, vol. 27, July, 1986, pp. 29-30.

Crutchfield, J. A., "An Economic View of Optimum Sustainable Yield." In *Optimum Sustainable Yield as a Concept in Fisheries Management*. Ed. W. F. Royce. Bethesda: American Fisheries Society, 1975, pp. 13-20.

Cushing, D. H., and J. W. Horwood, "Development of a Model of Stock and Recruitment." In *Fisheries Mathematics*. Ed. J. H. Steele. London: Academic Press, 1977, pp. 21-36.

Foster, J. J., R. S. T. Ferro, and A. J. Reid, "Analytic Approaches in Fishing Technology." In *Fisheries Mathematics*. Ed. J. H. Steele. London: Academic Press, 1977, pp. 21-36., pp. 99-116.

Harville, J. P., "Multidisciplinary Aspects of Optimum Sustainable Yield." In *Optimum Sustainable Yield as a Concept in Fisheries Management*. Ed. W. F. Royce. Bethesda: American Fisheries Society, 1975, pp. 51-64.

Kitsos, T. A., "Congress and the Oceans: Shaping Marine Policy for Three Decades," *MTS Journal*, vol. 22, 1988, pp. 33-49.

Lane, A. L., "Marine Resources Retrospective: Progress During the Last 25 Years," *MTS Journal*, vol. 22, 1988, pp. 71-77.

Mauerman, R. G., "Optimum Sustainable Yield in Inland Recreational Fisheries Management." In *Optimum Sustainable Yield as a Concept in Fisheries Management*. Ed. W. F. Royce. Bethesda: American Fisheries Society, 1975, pp. 39-44.

Radovich, J., "Application of Optimum Sustainable Yield Theory to Marine Fisheries." In *Optimum Sustainable Yield as a Concept in Fisheries Management*. Ed. W. F. Royce. Bethesda: American Fisheries Society, 1975, pp. 21-28.

Royce, W. F., "Use of Yield Models in Fishery Management." In *Optimum Sustainable Yield as a Concept in Fisheries Management*. Ed. W. F. Royce. Bethesda: American Fisheries Society, 1975, pp. 9-13.

Wooster, Warren S., ed. *Fishery Science and Management: Objectives and Limitations*, New York: Springer-Verlag, 1988.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center 2
   Cameron Station
   Alexandria, Virginia 22304-6145

2. Library, Code 52 2
   Naval Postgraduate School
   Monterey, California 93943-5101

3. Professor Katsuaki L. Terasawa, Code SM/Tk 2
   Department of Systems Management
   Naval Postgraduate School
   Monterey, CA 93943-5103

4. Professor Bill Gates, Code SM/Gt 2
   Department of Systems Management
   Naval Postgraduate School
   Monterey, CA 93943-5103

5. LT. Albert R. Costa 1
   AIMD
   USS Kitty Hawk (CV-63)
   FPOAP 96634-2770